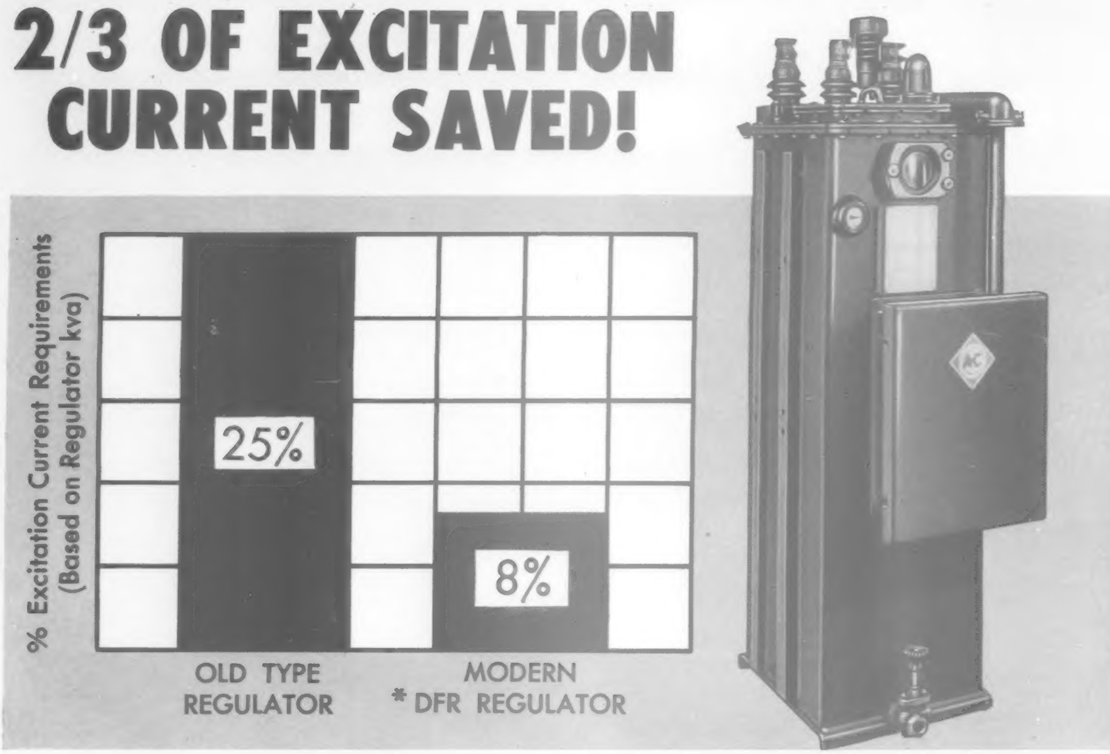
ALLIS-CHALMERS

Electrical Review

1st Quarter, 1947

2/3 OF EXCITATION CURRENT SAVED!



. . . with MODERN Allis-Chalmers *DFR — the Original 5/8% Step Regulator!

HERE'S AN ACTUAL CASE of a large utility. They bought 1,200 old type 100-kva regulators — a total of 120,000 kva installed capacity — before they heard about modern step-regulators.

Each old type regulator required 25% excitation or a total of at least 30,000 kva. *20,400 kva of that wattless current could have been saved by using Modern Allis-Chalmers step-type regulators!* That's because A-C's step regulators require only 8% excitation — a total of just 9,600 kva in this case.

Savings! In this case, a potential $142,800 worth — using DFR step regulators — figured on the basis of $7 per kva for installed capacitors needed to balance 20,400 reactive kva.

And look at equipment cost! This utility figured they were using over $1,000,000 worth of equipment for unnecessary excitation of their old type regulators.

Yes, figure the savings that DFR step-regulators could make on your system!

For further details on how you can save 2/3 excitation current, call your nearby Allis-Chalmers office, or write ALLIS-CHALMERS, MILWAUKEE 1, WIS.

***DFR** — the only station type step regulator you can buy for single phase duty.

1 GET CLOSER REGULATION!

Modern DFR step regulator with its Feather Touch control and voltage integrating relay eliminates holding coils — resulting in closer control.

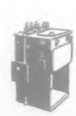
2 . . . AND LOWER OVER-ALL MAINTENANCE!

Complete oil immersion of all moving parts—even the driving motor—eliminates the need for other lubrication. In addition, because the energy handled by the relay contacts is small, no compounding or holding coils are required. Further, this rugged regulator employs self centering shock absorbing, "quick-break" mechanism and arc resisting long-lived Elkonite RS-1045 contacts.

A 2242

The Only Complete Line of 5/8% Step Regulators

AFR — for 3-phase regulation up to 69 kv, 750 kva.

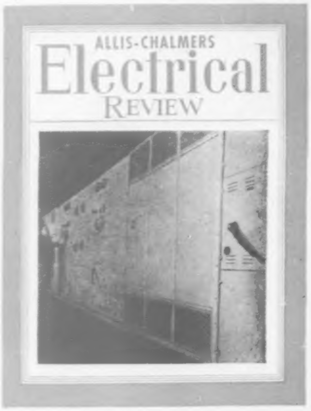


DFR—for single phase regulation up to 6,900 v, 250 kva.

ALLIS-CHALMERS

One of the Big 3 in Electric Power Equipment — Biggest of All in Range of Industrial Products

1847 1947 A CENTURY OF SERVICE to Industry THAT MADE America Great



SUPPLYING D-C POWER for the shops of a foundry specializing in heavy castings for railway equipment, this 600 kw rectifier of unit substation type is typical of units in demand for new buildings or for replacement of old equipment in expanding plants.

Here, two identical 300 kw rectifiers, which can be run individually or in parallel, feed common buswork for the d-c system.

★

Vol. XII . . No. 1

Allis-Chalmers
Electrical Review

Issued quarterly. Subscription rates: U. S., Mexico, and Canada, $2.00 per year; other countries, $3.00. Address Allis-Chalmers Electrical Review, Milwaukee 1, Wisconsin.

Printed in U. S. A.

★

ALLIS-CHALMERS Electrical REVIEW

★

Contents

★

Electrical Energy on Wheels!

W. E. SCHWARTZBURG
Mixed Apparatus Sales
Allis-Chalmers Mfg. Co.

Mobile substations have come of age within the last few years. Today's standards of design and performance are told by the author.

THE mobile unit substation is essentially a light weight, factory assembled substation mounted on a pneumatic tired trailer. Consisting of high voltage equipment, transformer and low voltage switchgear, the mobile substation is a relatively new member of the standard multi-circuit, single circuit and load center unit substation line. The mobile sub has received widespread acceptance by electrical utilities throughout the country because it has answered many distribution problems which were heretofore very difficult to solve. These easily moved units offer utilities an inexpensive way of solving three distribution problems with a single unit, by providing spare capacity for abnormal loads anywhere on the system, providing replacement facilities during maintenance down-time on permanent substations, and insuring immediate switching and transformer facilities needed in emergencies.

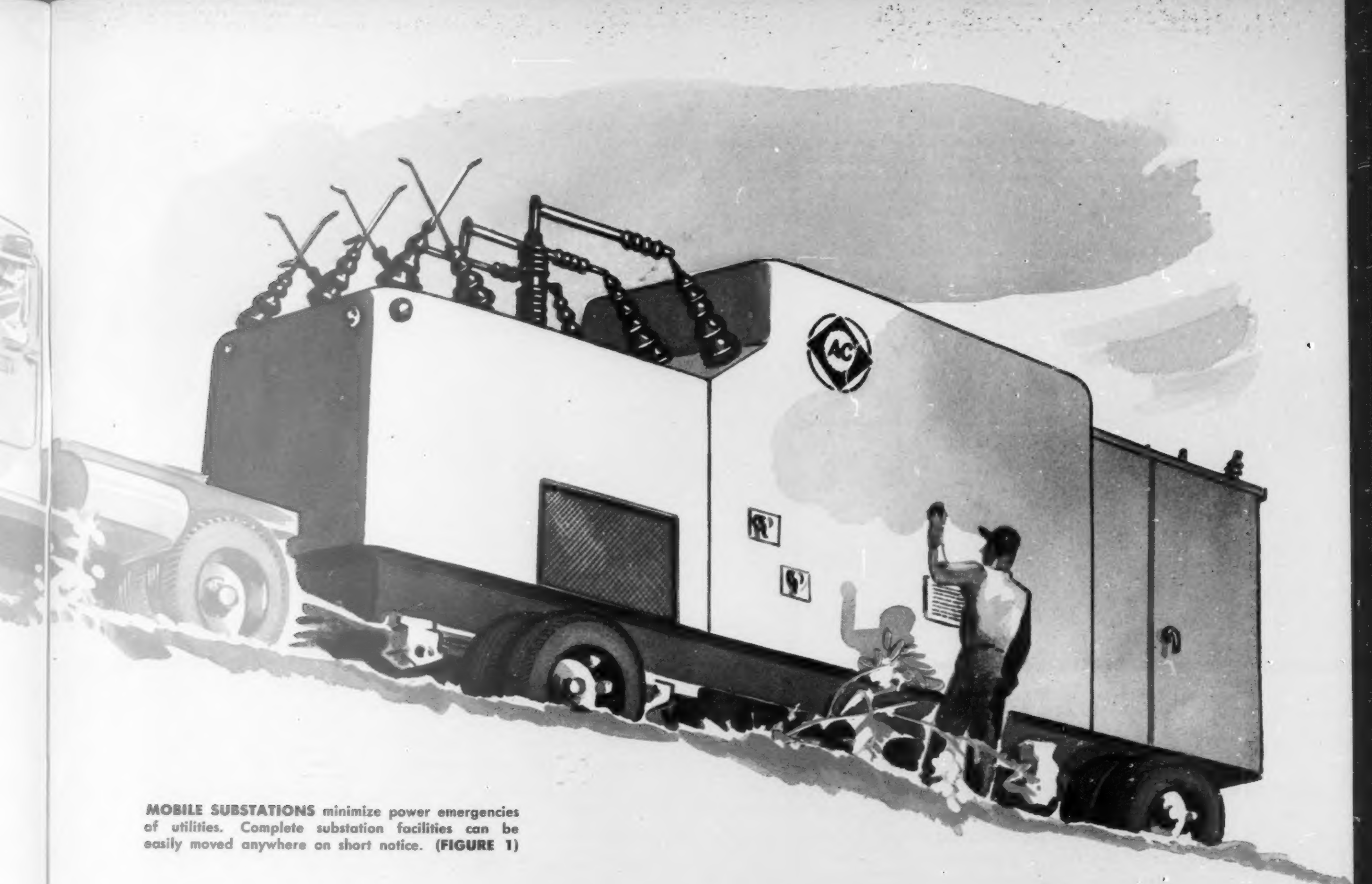
Mobile unit substations are now considered standard in capacities from 750 to 3,750 kva. As the greatest weight is in the transformer core, coil, and oil, this portion of the unit is designed as compactly as possible. It is for this reason that all standard mobile unit substation transformers are normally supplied with forced-air or forced-air/forced-oil cooling, depending upon the size. Standard units are designed to operate on voltages up to 69 kv, although custom-built portables have been designed for operation on 115 kv. Metal enclosed switchgear of a special compact design is incorporated to help keep weight at a minimum. To illustrate these points each component part of a typical mobile unit shown in the single line diagram in Figure 2 will be analyzed.

Special primary construction required

The three pole, single throw, group operated, air-break disconnect switch is normally mounted on the front of the unit. As the overall width of the substation (while being towed on the highways) is generally limited to eight feet, it is sometimes necessary to supply the incoming line switch on a telescoping base. To maintain NEMA phase spacings while in operation, the poles of the switch are built on a sliding base which can be collapsed when the substation is in transit. This type of construction is used on substations designed for 44 kv service and above. The NEMA standard phase spacings for horn-gap disconnect switches, based on the EEI schedule of system voltages using AIEE standards as a basis, are as follows:

Voltage	Phase Spacing
15 kv	36 inches
22 kv	48 inches
33 kv	60 inches
44 kv	72 inches
66 kv	84 inches

The horn-gap switch is of either the rotating or tilting insulator type, depending upon the voltage. Normally the arcing horns are removed while the substation is being moved. This switch is designed for ground level operation and will make and break the magnetizing current of the transformer. The standard switch is also supplied with provision for padlocking to prevent accidental operation under load, as well as



MOBILE SUBSTATIONS minimize power emergencies of utilities. Complete substation facilities can be easily moved anywhere on short notice. **(FIGURE 1)**

clamp type terminals for terminating a slack span of the high voltage line.

Mounted as an integral part of the substation are three line type lightning arresters, placed vertically behind the disconnect switch. Special braces are used with the high voltage units in transit so that the arrester will not be damaged by jarring. As the mobile unit substation is often designed for two or more primary voltages, the lightning arrester must be designed to provide protection for any voltage on which the transformer can operate.

Although line type lightning arresters are standard on mobile unit substations, some users request the station type arrester. While, of course, station type lightning arresters can be supplied, their superior electrical characteristics should be weighed against their added weight and size. The station type arrester weighs approximately 300 percent as much as the line type and is about 25 percent taller for the same voltage class.

High voltage, non-expulsion type fuses are mounted between the lightning arresters and the transformer, and provide protection for the mobile unit substation and the system upon which it is operating. Since the fuse element is of the non-expellent type, the danger of the fuse spraying other equipment when opening is eliminated. This allows standard phase spacing throughout the substation. It should be noted that the fuses are placed behind the lightning arresters so that they will not be required to carry the currents following a lightning discharge.

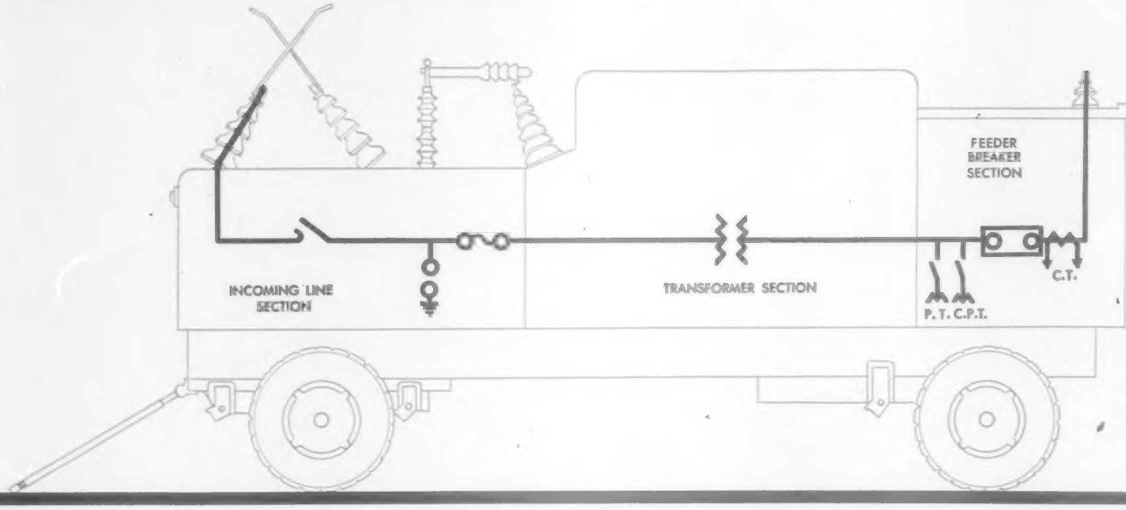
One complete set of fuses with three replacable elements are considered standard equipment; however, when the unit is designed to operate on several voltages it is also necessary to supply fuse elements of the correct ampere rating for each of the voltages at which the unit substation will operate. As the fuses are removed while the unit is in transit, storage facilities are provided for the fuses as well as the spares.

Transformer section needs careful design

Supporting the load side of the fuses are the transformer high voltage bushings which are mounted towards the front of the transformer section. Since the transformer section is always the heaviest portion of the substation, every consideration is given to the design of the tank, core, coils, and method of cooling. Completely interleaved, low loss silicon steel is employed for the transformer core. The clamping action of heavy steel bolts and channel sections holds the core steel in place with no bolts passing through it. This type of construction not only insures even flux distribution and eliminates the possibility of short circuiting laminations but also insures the great mechanical strength necessary for a mobile substation.

Because mobile unit substations are often called to operate on several different line voltages, the transformer windings are designed in sections which can be connected in series or parallel. Provision is also often made for connecting the transformer in delta or wye. The winding connection is changed by a handwheel located on the side of the transformer case.

A TYPICAL MOBILE SUB, with line drawing superimposed, shows the placement of essential circuit elements. Location of components shown below is considered the most practical in the majority of cases. (FIGURE 2)



In smaller kva ratings the units employ the conventional type transformer tank with forced-air cooling only. A sufficient number of propeller type fans are mounted at the base of the radiators and are automatically controlled. In this type of construction the transformer capacity is reduced about one-third when the fans are not operating. The fans are controlled from the winding temperature through the use of a thermal relay. When excessive temperature is being approached, a warning signal is energized; if the overload persists the fans are started. On large units the breaker is interlocked with the cooling equipment so that the transformer can not carry load unless the cooling equipment is functioning correctly.

Other standard transformer accessories which are included on mobile unit substations consist of magnetic liquid-level gauge, liquid drain and sampling valves, filter press connections, necessary handholes in the transformer tank, and an oil temperature indicator.

Breakers electrically operated

Secondary bushings of the transformer are brought through the tank wall into the switchgear section, which is a weatherproof unit mounted at the rear of the trailer. Because the secondary voltage of the transformer is limited to 15 kv and below, standard frame mounted circuit breakers are used. This breaker is available in standard interrupting capacities from 50,000 to 500,000 kva. All breakers are electrically operated through the use of a control transformer which supplies 220 volts to the rectifier, which, in turn, supplies d-c power to the closing coil of the breaker. The breaker is usually equipped with a-c tripping by over current induction type relays. A position indicator, operation counter, auxiliary switches, and control relay are included as part of the breaker equipment.

Three current transformers, over-current relays, a three-shot reclosing relay, an ammeter, voltmeter, and transfer switches, and a three-element watthour demand meter are also considered standard equipment for the mobile substation. Other relays and meters can be included, though the number is normally minimized to keep within space and weight limitations. Relays are of the drawout type and are mounted on a swinging panel (Figure 3) with the meters.

The potential, control and current transformers are designed to operate correctly on any of the secondary voltages which the transformer can supply. This permits operation of the main transformer winding on any connection without making major changes in the instrument and control transformers.

Space heaters, light sockets and switches as well as convenience outlets are included and space is also provided for storage of the spare fuses, tools and other necessary operating equipment. The low voltage line connection is normally made through root-bushings mounted on the top of the switchgear unit. When desired, lightning arresters can also be mounted on the top of the unit, adjacent to the bushings. A collapsible frame for mounting disconnect switches can also be supplied, although they are not standard equipment.

Trailer section

The trailer on which the electrical equipment is mounted is usually a two-axle full trailer. On the larger units, due to increased weight, it is sometimes necessary to supply a tandem rear axle. Some state laws, however, permit only the use of semi-trailers.

Because the type of trailer is often dictated by highway size and weight limitations in varying state laws (Figure 5), close attention must be given to these laws by both the manufacturer and the user.

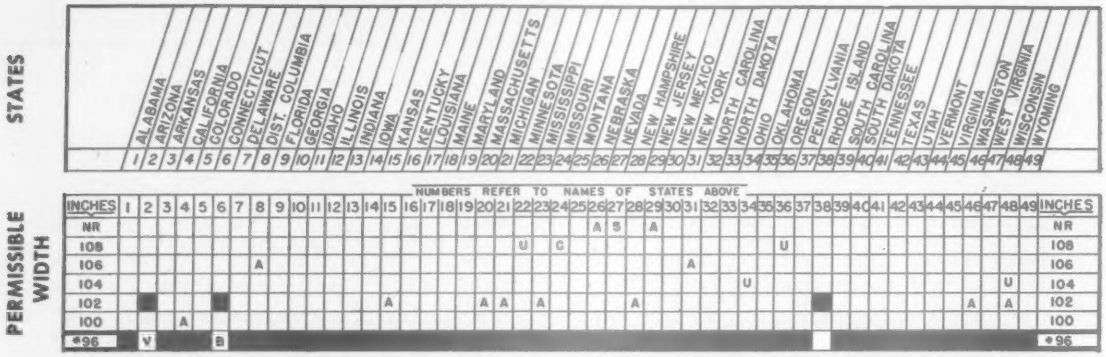
An earnest attempt is being made to standardize state highway laws. It should be noted that almost all state laws are written so that oversize and overweight permits may be issued by the local authorities.

Tire size on the trailers vary, depending on the load, although the most popular size seems to be 10 by 20, 12 ply.

CORE AND COILS of a 2,500 kva mobile substation being lowered into transformer case. High voltage fuses are not incorporated in this unit. Low voltage disconnects will be mounted above bushings. **(FIGURE 3)**

COMPACT DESIGN features a movable control panel which, when swung out, reveals the oil circuit breaker operator on the right. Control panel carries practically all standard metering equipment. **(FIGURE 4)**

LEGAL MAXIMUM SIZE LIMITS



#—AASHO'S RECOMMENDED LOWEST MAXIMUM

A—PERMITTED AT WHEELS WHEN PNEUMATIC TIRES ARE SUBSTITUTED FOR OTHERS

B—PERMITTED PUBLIC SERVICE VEHICLES

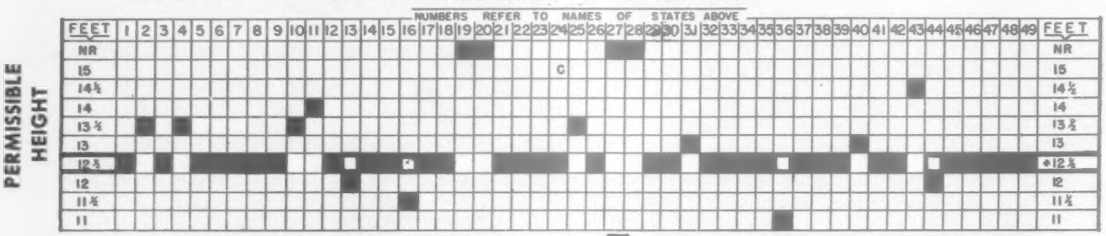
C—PERMITTED IN CITIES HAVING 75000 POPULATION

S—SPEED OF VEHICLES OVER 96 INCHES WIDE NOT TO EXCEED 5 MILES PER HOUR

U—PERMITTED URBAN BUSES

V—BODY WIDTH

NR—NO RESTRICTIONS



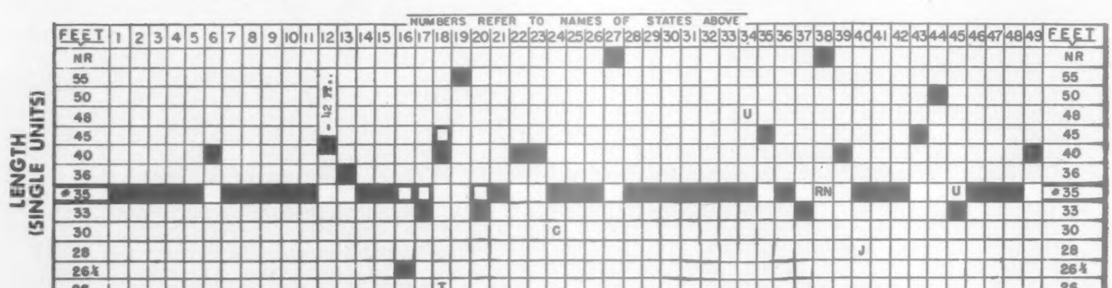
#—AASHO'S RECOMMENDED LOWEST MAXIMUM

C—PERMITTED IN CITIES HAVING 75000 POPULATION

NR—NO RESTRICTION

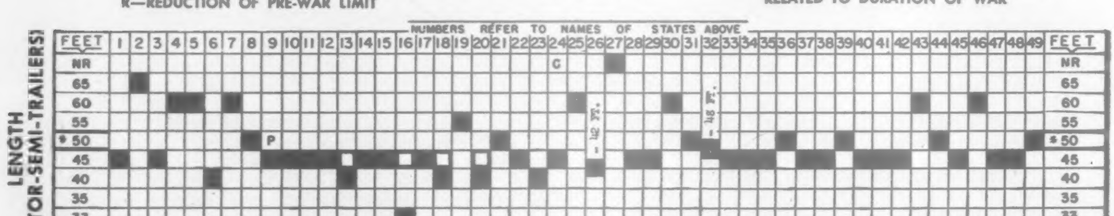
■—PRE-WAR LIMIT WHICH HAS NOT BEEN CHANGED UNLESS OTHERWISE INDICATED

□—SPECIAL LIMIT MORE OR LESS CLOSELY RELATED TO DURATION OF WAR



#—AASHO'S RECOMMENDED LOWEST MAXIMUM
C—PERMITTED IN CITIES HAVING 75000 POPULATION
J—BUSES UNDER JURISDICTION OF RAILROAD COMMISSION
N—NEW LIMIT NOW EXISTING (NOT RESTRICTED TO THE DURATION)
R—REDUCTION OF PRE-WAR LIMIT

T—LIMIT ON FULL TRAILERS
U—URBAN BUSES
NR—NO RESTRICTION
□—SPECIAL LIMIT MORE OR LESS CLOSELY RELATED TO DURATION OF WAR



#—AASHO'S RECOMMENDED LOWEST MAXIMUM

C—PERMITTED 85 FEET IN CITIES HAVING 75000 POPULATION

P—FOR HIRE VEHICLES

NR—NO RESTRICTION

□—SPECIAL LIMIT MORE OR LESS CLOSELY RELATED TO DURATION OF WAR

HIGHWAY SIZE LIMITS vary according to states and must be considered when planning mobile substations. All states have special permits for movement of oversize equipment. Table reprinted from the Highway Restrictions Handbook of the National Highway Users Conference, Inc. (FIG. 5)

Some overloading of tires is not considered objectionable, since the number of miles put on a mobile unit substation is very small compared to normal mileage on a truck or trailer unit and since adjustable jacks are provided to take the load off tires when the substation is not in transit.

When shipped from the manufacturer, the mobile unit substation is a complete unit with the trailer assembled and co-ordinated with the electrical equipment and all accessories ready for use. Each piece of electrical equipment is tested in accordance with applicable AIEE and ASA standards.

Economics of mobile substations

Summarizing the foregoing discussion, standard mobile unit substations are available in capacities of 750 to 3,750 kva with high voltage ratings from 15 to 69 kv, and low voltage ratings 15 kv and below. These standard ratings represent the practical limits to which the manufacturer can go today without exceeding weight and dimension limitations set forth by state highway laws. Whenever a special unit is desired, careful consideration should be given to the advantages and disadvantages to be obtained. The following special ratings or designs should be avoided if at all possible:

1. Special features
2. Voltage ratios
3. Load-ratio-control equipment
4. Special efficiencies
5. Voltages above 69 kv
6. Units below 750 kva

1. *Special features* — requirements such as low exciting current, subnormal noise levels, low reactances, and short-time overload characteristics are features which, when specified, handicap the designer. Many special features which are available in standard multi-circuit and single circuit substations are very difficult, if not impossible, to supply in a mobile unit without subordinating the desirable features of the mobile substation.

2. *Voltage ratios* — It is usually considered advisable to build the transformer section with windings which will allow operation on most of the voltages encountered on the user's system. This is usually done by employing an externally operated switch which will connect the winding in the desired way. To utilize the full transformer kva, the voltages specified should be voltages which can be obtained through the use of series-parallel or delta-wye connections. For instance, the high voltage winding, through the use of a series-parallel connection, can be made to operate on 22,000 or 44,000 volts at full rated kva. However, if the transformer must be designed to operate at 22,000 and 33,000 volts it would be impractical to connect the windings so that full kva would be available at both voltages. If the low voltage winding is built with three 2,400 volt sections per phase, it would be possible to obtain 2,400 volts with the three sections in parallel connected delta, 4,160 volts wye; 7,200 volts delta with the three sections connected in series and 12,470 volts wye. These voltages could be obtained at the rated kva of the transformer. In general, multiple voltage ratings that can be obtained with a two-to-one series multiple or wye-delta connection in the high winding and two-to-one or three-to-one series multiple and wye-delta in the low voltage winding should be considered. Utilizing these types of transformer connections will permit the most efficient operation of the unit.

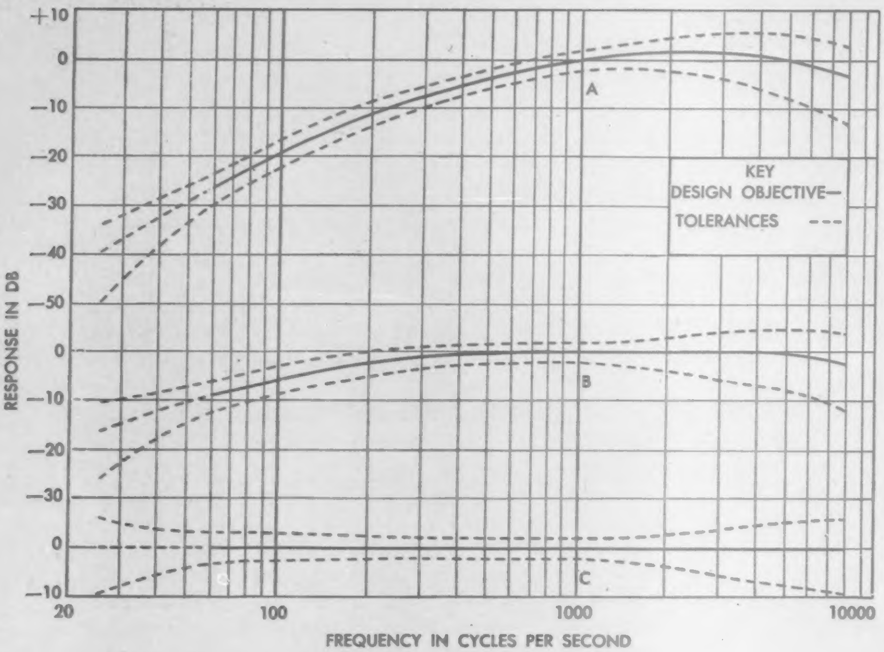
3. *Load-ratio-control equipment*—although automatic load-ratio-control equipment can be supplied on any power transformer its added weight prevents the manufacturer listing it as standard equipment. Special designs, smaller units, and increased shipping times are involved when it is specified. The addition of the tap changing under load equipment adds from 15 to 25 percent to the total weight of the mobile unit substation.

4. *Special efficiencies* — the no-load losses of the mobile transformer are approximately the same as those of a standard power transformer, but the total losses run about 50 percent more than a conventional unit. The substation is in service for short periods of time and this should be considered when losses are evaluated. The losses selected in design represent a balance between the type of cooling, the weight of the material used in the core, coils and tank, and the use of standard fans, pumps, and other auxiliaries. If special losses are required this balance is upset and again special equipment must be used.

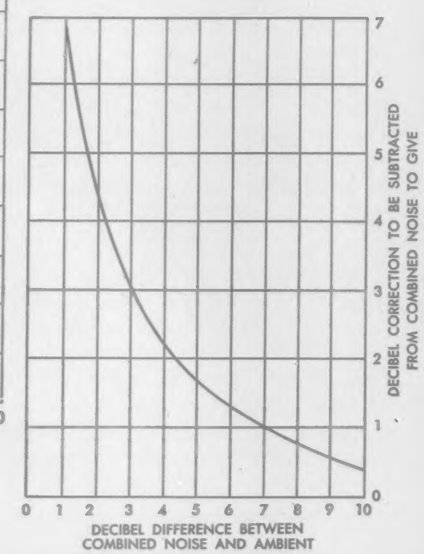
5. *Voltages above 69 kv* — since high voltage switching equipment is designed to operate with air clearances, many problems appear when 69,000 volts is exceeded. Take, for example, the high voltage switch. The standard phase spacing for 69 kv service is 7 feet, while the standard spacing for 115 kv service is 10 feet. This means that in the operating position the three poles of the switch would require a space of 20 feet. The 115 kv unit would weigh approximately twice as much and the vertical dimension of the switch would also increase. Weight and dimensions of the lightning arresters would be increased. As a great portion of the transformer weight would be consumed by insulation instead of copper the maximum kva would be limited.

6. *Units below 750 kva* — as the mobile unit substation is based upon combined cost of the component parts, the cost of the trailer does not vary to a great extent from the small to the large units. Cost of the high voltage switch, lightning arrester, and fuse is almost constant for a given voltage rating. Interrupting capacity of the low voltage breaker varies as the kva of the substation and the kva which the primary system is capable of supplying under fault conditions. The actual interrupting capacity of the secondary breaker usually varies from 50 to 150-thousand kva. The largest variation in cost is that of the transformer itself. When the capacity falls below 750 kva, the price per kva soars. In most cases, the smaller kva ratings are desired for application on 600 volts or less and a standard load center substation mounted on skids or a truck is normally more economical for this service.

Having found widespread approval throughout the United States as well as in many war-torn countries of the eastern hemisphere, the practicability of the standard mobile unit substation has filled a long-felt need for this type of equipment. Through the application and use of such mobile units utilities are able to offer more dependable and reliable service to the ultimate consumer of power and to make easier the inspection and maintenance of distribution equipment.



ALLOWABLE DEVIATIONS of over-all free-field frequency response characteristics and tolerances for sound level meters. Reprinted from ASA Standards Z24.3-1944. **(FIGURE 4)**



CORRECTION FACTORS shown above are needed to adjust sound level meter readings when ambient noise is within 10 db of the combined sound level. **(FIG. 5)**

Is it Sound ... or *NOISE?*

PART TWO OF TWO PARTS

L. C. AICHER
Transformer Section
Allis-Chalmers Mfg. Co.

SOUND has been defined in its psychological and physiological aspects by a discussion in the first part of this article of the terminology of acoustics and the characteristics of sound waves. Of most concern to the engineer are the physical phenomena which produce sound, and the instruments and procedures used at present to analyze sound and reduce noise.

In reducing noise, it is advisable to make an accurate determination of sound intensity before making a serious effort to reduce this intensity. This data serves as a basis for comparison to ascertain any improvement which may be achieved.

The basic instrument used is the sound-level meter, sometimes called a noise meter. This is essentially a device for measuring the amplitude of rapid alterations in air pressure, but not for measuring the frequency at which the alterations take place. It consists of an amplifier to increase the voltages generated in the microphone, and an indicating instrument to read the magnitude of the applied signal. An attenuator or range selector can be varied, usually in 10 decibel steps, over the entire range of the instrument. Most instruments cover the range from about 20 to about 130 decibels.

Although it is desirable to have the sound-level meter simulate the human ear in its frequency-response characteristic, for practical reasons of instrument design and economy the simulation is only approximate. Since the response curve of the ear is not constant, but varies with level, it is indicated that the sound-level meter should have many responses to simulate the ear. But an unnecessarily complicated, bulky, and expensive instrument would result, so a compromise which includes three definite frequency responses is reached. These ear weighting characteristics are accomplished by electrical filter circuits and are approximations to the 40, the 70, and the 100 phon loudness-level contours. The latter is simulated by a flat response characteristic. A sound-level meter would read loudness-level in phons if the simulation were per-

fect. However, because it is only approximate, the term sound-level is used to describe the instrument reading, and it is expressed in decibels.

Limitations of sound-level meter

When using the flat-response network, the sound-level meter measures sound-pressure level in any kind of sound field. With the flat response setting, the instrument reads intensity level, in decibels, but only in a plane or spherical sound wave such as is radiated from a point source in a free field. If the intensity level under any other field condition is desired, it is necessary to measure the pressure, particle velocity, and phase relation for each frequency component present. This process practically requires laboratory facilities and technique and cannot be considered a commercial test facility.

Sound-level meters vary little in design, conforming to standards set by the American Standards Association. For most purposes they may be considered interchangeable, although in some cases their readings will not be identical. A glance at Figure 4 will show one reason why this occurs. The tolerances are rather wide, but one acquainted with acoustical measurements knows these are necessary because of the limitations of available microphones.

Frequency characteristics of standard microphones vary considerably from a straight flat line, particularly in the extreme upper and lower parts of the audible range. In most cases, the microphones used for sound measurement are improved in this respect over those commonly used for broadcasting and recording, although the perfect microphone is yet to be developed. Available microphones represent a compromise to get the best possible combination of good frequency response, stability, ruggedness, and sensitivity. The tolerances of Figure 4 represent the maximum departure to be expected from the best microphones used on sound-level meters. Electrical circuits in the sound-level meter can be made to follow any particular characteristic desired with a high degree of accuracy.

To the engineer concerned with analyzing sound and reducing it effectively, the instruments and procedures discussed here can be of invaluable aid.

It is easy to see that factory sound-level measurements made with a particular meter may not compare exactly with field measurements on the same machine made with a second sound-level meter. Such comparisons are of little value unless a comparison of the two sound-level meters is possible. If sound-level meter measurements are going to be compared like those of voltmeters, ammeters, wattmeters, and the like, then there is a need for better calibration methods.

Sound-measuring technique

An AIEE test code has been prepared which outlines certain standard methods of procedure. It is not complete, nor does it apply in all cases, but it does form a guide where specialized codes are not available. Best results are obtained when sound measurements are made in locations where reflections from nearby objects and standing wave patterns are at a minimum. Since most apparatus measurements are made only a few feet above ground, it is desirable that the ground surface be as absorbent to sound as possible to minimize reflections. Likewise, walls and other objects in the immediate vicinity should be lined with sound absorbent material to minimize reflections, and should be kept as far from the sound source and measuring equipment as possible.

To promote uniformity and to facilitate comparison of measurements, standard distances from the microphone to the apparatus are recommended. These distances are ½ foot, one foot, and three feet. The distance should be measured to the major surface, disregarding minor projections, and the microphone placed in a position free from disturbing air currents, vibration, magnetic or electric fields, or other external influences that may affect the readings.

Ambient sound-level should be at least 6 db, preferably 10 db or more, lower than the sound-level caused by the apparatus. Since this is not always possible, a correction can be applied (Figure 5) to provide a means of approximating the sound-level. This correction must be considered an approximation unless it is known that the sound field is in free space. Measurements of the sound radiated by the apparatus can be made to approximate the average sound-level produced by the apparatus under free field conditions by making a large number of measurements near the apparatus.

When obtaining an average sound-level figure from a group of sound-level readings taken around a machine, the average energy method is the most accurate. The average energy is defined as 10 times the logarithm to the base 10 of the average of the antilogarithms of 1/10 of the separate decibel values. An example will illustrate this method.

Microphone Position	Sound Level	Antilogarithm (as defined)
A	40	10,000
B	60	1,000,000
C	50	100,000
		1,100,000 Total

$$\text{average} = \frac{1{,}100{,}000}{3} = 370{,}000$$

$10 \log_{10} 370{,}000 = 55.7$ db average sound-level

Where the range of differences of readings to be averaged is 12 db or less, the arithmetic average of the decibel readings is a sufficiently close approximation for normal use.

Next, it is necessary to decide which ear weighting characteristic is to be used before a sound measurement series is undertaken. Changing the weighting curve can produce variations in the results ranging from negligible in the medium and upper frequencies to variations of 20 to 30 decibels at low frequencies. When only knowledge of the sound-level at the microphone is desired, the following sound-level ranges and weighting curves are usually used:

Sound-Level Range	Weighting Curve (In Figure 4)
25- 55 db	A (40 db)
55- 85 db	B (70 db)
85-140 db	C (Flat)

Apparatus sound-level measurements are usually made with

curve A (40 db) weighting. This practice is supported by the fact that it is important to have sound-level measurements representative of the level that is actually heard under operating conditions. If the apparatus sound-level is high, the apparatus is usually placed remote from the point where quietness is desirable. At the point in question, the sound-level actually heard is much lower than that measured at the machine and it is desirable to make the measurements with the weighting curve corresponding to the lower level. This is the A curve (40 db). In all cases, it is desirable to record the weighting curve as well as the decibel values read, the temperature existing at the time the measurements are made, and whether an extension cord was used on the microphone. This data permits the application of correction factors to rectify the data into the most accurate commensurate with present day equipment.

If all these precautions and corrections are necessary, why use a sound-level meter? Any instrument can be used more intelligently when its limitations as well as its advantages are known and respected. The limitations are inherent in the present state of the art and do not make the instrument useless. On the contrary, the meter's characteristics are more useful than if it followed the ear exactly. The more important advantages of the sound-level meter are:

1. It gives a definite numerical reading which can be duplicated quickly, and which can be kept as a permanent record.
2. It can detect slight changes in level imperceptible to the ear. An accumulation of small changes can add up to definite improvement.
3. Frequency characteristic of the meter can be adjusted independently of the sound level.
4. It can, for purposes of physical analysis, provide unweighted readings in terms of actual sound pressures.
5. Its readings are unaffected by the many human variables which enter into any sort of loudness estimates.
6. It is unprejudiced by likes or dislikes for particular types of sound.

Analysis of noise

Only weighted or unweighted sound pressures are measured by the sound-level meter. If a more complete description of the sound is desired, measurements including pitch and quality are also needed. The common mathematical concept of a complex sound or vibration is based upon the Fourier system of analysis. This divides any complex waveform into a series of sinusoidal waveforms of different frequencies and of definite amplitudes and phase relationships.

In general, what the ear recognizes as pitch is the frequency of the lowest-frequency sinusoidal component in the complex waveform. The higher frequency components are generally, but not always, harmonics of the fundamental, and determine the quality or timbre of the sound. It is the different high frequency components produced by the various musical instruments which give each its recognizable characteristic sound quality. Except under unusual conditions, the phase of the components does not affect the ear and hence is unimportant for purposes of noise measurement.

Machinery noises may be divided into two general classes, the "pitched" noises and the "unpitched" noises. Pitched noises are those whose fundamental frequency and harmonics vary in frequency proportionately with fundamental operational characteristics of the machine, such as speed, excitation requency, slip frequency, or the like.

Unpitched noises include those not definitely related to speed or excitation frequency or any other operating characteristic. The unpitched sound generating vibrations are usually caused by shock excitation at the machine fundamental speed or some harmonic of it. A seriés of damped waves is produced whose components correspond to the natural frequency or harmonics of the vibrating parts. The actual frequencies involved are seldom clearly defined since the effects of shock excitation, the natural damping of mechanical parts, the movement of parts, and the variation of forces impressed upon the parts cause appreciable frequency variation. The sound energy of these noises is generally distributed over frequency bands.

Both pitched and unpitched components are contained in the noise of most machines. Usually most of the disturbing sound energy falls into either one class or the other. The hum of a transformer is an example of a pitched sound and that of a boiler shop is unpitched. Since all these complex sound pressure waveforms can be translated into electrical voltages having corresponding forms, the frequency composition of the sound can be found if these electrical waveforms can be analyzed by selective filtering of the complex waveform in terms of components of known frequencies and measurable amplitudes. Frequency analyzers exist in many forms. The most appropriate analyzer for noise analysis possesses a constant-percentage-of-frequency selective network and is known as a degenerative type analyzer.

Before making an analysis it is necessary to decide whether it is the measurement of the amount each component contributes to the sound as heard by the ear that is desired, or whether it is a direct physical measurement of the relative intensity of each component. If the first is desired, the same weighting curve should be used as when measuring the noise with the sound-level meter alone. If a direct physical measurement is desired, the C or flat response should be used.

Sometimes it is advantageous to use a recording frequency analyzer that draws a curve of the sound-level of each frequency as it scans the audible range. This record can be studied at leisure and permanently filed.

Vibration measurement

That sound is produced by mechanical vibrations is a fundamental concept, but the relationships between the two and their effects upon human beings is extremely complex. We have been considering sound as fluid-borne, usually airborne, vibrations within the audible range. The term vibration is used here to mean mechanical vibrations in solids. The basic equations apply to vibrations as well as sound upon substituting the appropriate variants.

Vibrations, like linear and angular motion, can be measured in terms of displacement, velocity and acceleration. The simplest measurement is displacement, which is expressed as

$$y = y_m \sin \frac{2 \pi t}{T} \qquad (3)$$

Displacement, however, is not always the most important property of vibrations. A mechanical part that is vibrating may be compared with a loudspeaker. The velocity of the

radiating part and that of the air directly next to it will generally be the same, so, as long as the distance from the front of the radiating part to its back is large compared to one-half the wave length of sound in air, the sound pressure generated in the air will be proportional to the velocity of the vibrations.

The sound energy radiated is the product of particle velocity squared times the acoustic resistance of the air load. Under these conditions it is the velocity of the vibrating part rather than its displacement that is of greatest importance. The velocity is the first derivative of the displacement, so for the simple harmonic vibration of equation 3, the velocity is

$$v_m = \frac{dy}{dt} = \frac{2\pi}{T} y_m \cos \frac{2\pi t}{T} \quad \text{(4)}$$

Thus, the velocity is related to the displacement and the frequency of the vibration.

Mechanical failure can be produced by vibrations. Also, there is sound generated by the vibrations. Newton's laws of motion state that the acceleration of a given mass is proportional to the applied force, and that this force produces a reacting force which is equal to it but opposite in direction. Any stresses, resulting in strain, set up in a vibrating body are, therefore, proportional to the acceleration of the vibration, which is the second derivative of the displacement, thus:

$$a = \frac{dv}{dt} = \frac{d^2y}{dt^2} = \frac{-4\pi^2}{T^2} y_m \sin \frac{2\pi t}{T} \quad \text{(5)}$$

Acceleration, therefore, is proportional to the displacement and to the square of the vibration frequency. Other valuable expressions commonly used in sound and vibration analysis are contained in equations 6 through 17.

A device that responds to mechanical vibrations in a manner similar to the response of a microphone to air-borne vibrations is a vibration pickup. It can be substituted for the microphone and the sound-level meter used in a normal manner. One type of pickup is of the inertia-operated piezoelectric type and responds to acceleration. Suitable electrical integrating circuits can be inserted between the pickup and the sound-level meter that will convert the response to read particle velocity or displacement. Another type of pickup responds to displacement.

The readings obtained on the sound-level meter will be in decibels which are rather meaningless as units of displacement, velocity, or acceleration. However, these numerical quantities in decibels can be converted to the more logical units of micro-inches, micro-inches per second, or inches per second per second.

Thus, it is apparent that the several sound measuring and frequency analyzing instruments are invaluable aids to an effective program of noise reduction. Meter readings alone are usually beneficial only when they are reduced to the physical phenomena that gives rise to the sound, and the engineer's efforts are confined to the control of these phenomena. As more experience is gained, it can be hoped that better instruments will become available. Likewise, experience will undoubtedly produce a better understanding of noise, what makes it, how to measure it, and what methods to employ to reduce it.

★ ADDITIONAL ★ PHYSICAL RELATIONSHIPS

Wave Velocity (velocity of propagation)

$$V = f\lambda \quad \text{(6)}$$

V in air at 0° C and 76 cm, pressure—1,088 ft per sec

V in water—4,800 ft per sec

V in steel—16,410 ft per sec

Wave Velocity in Solids

$$V = \sqrt{\frac{K}{D}} \quad \text{(7)}$$

Wave Velocity in terms of Pressure and Density

$$V = \sqrt{\frac{\gamma P}{D}} \quad \text{(8)}$$

Influence of Temperature (of a gas) on Wave Velocity

$$\frac{V_{t1}}{V_{t2}} = \sqrt{\frac{T_1}{T_2}} \quad \text{(9)}$$

Influence of Moisture (in a gas) on Velocity

$$\frac{V_{wg}}{V_{dg}} = \sqrt{\frac{D_{wg}}{D_{dg}}} \quad \text{(10)}$$

Acoustic Resistance

$$R = DV \text{ in liquids} \quad \text{(11)}$$

$$R = \sqrt{KD} \text{ in solids} \quad \text{(12)}$$

$$R = \sqrt{\gamma PD} \text{ in gases} \quad \text{(13)}$$

Intensity of a Plane Wave in the Direction of Propagation

$$I = \frac{p_m^2}{2DV} \quad \text{(14)}$$

Intensity from a Sphere (Simple Source)

$$I \cong \frac{2\pi^2 f^2 D r^4 v_m^2}{V d^2} \quad \text{(15)}$$

Intensity from a Cylinder

$$I \cong \tfrac{1}{2}\pi^2 D r^2 v_m^2 \, \frac{f}{d} \quad \text{(16)}$$

Intensity from a Vibrating Wire

(Lateral vibration perpendicular to its axis)

$$I \cong \frac{2\pi^4 f^3 D r^4 v_m^2 \cos^2\phi}{V^2 d} \quad \text{(17)}$$

BIBLIOGRAPHY

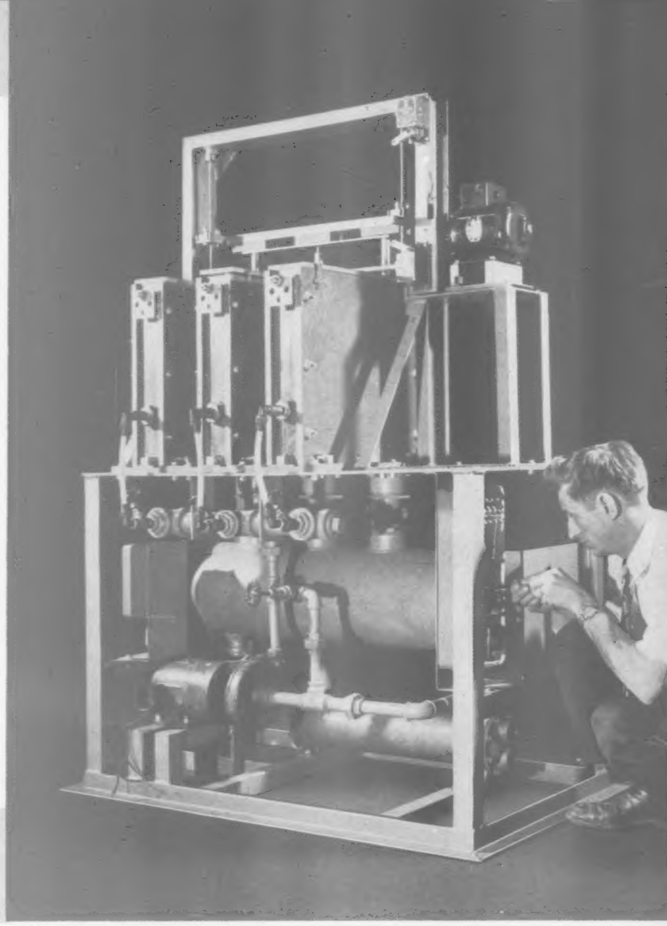
1. Acoustic Terminology, American Standards Association, Z24-1—1942.
2. Noise Measurement, American Standards Association, Z24.2—1942.
3. Sound Level Meters for Measurement of Noise and Other Sounds, American Standards Association, Z24.3—1944.
4. AIEE Test Code for Apparatus Noise Measurement, American Institute of Electrical Engineers, AIEE—No. 520, 1939.
5. Transformers That Only Whisper, L. C. Aicher, Allis-Chalmers Electrical Review, June, 1943.
6. Sound Waves and Acoustics, M. Y. Colby (a book), Henry Holt and Company.
7. Vibration and Sound, Morse (a book), McGraw-Hill.
8. Applied Acoustics, Olson and Massa (a book), Blakiston.
9. Theory of Vibrating Systems and Sound, Crandall (a book), D. Van Nostrand.
10. Speech and Hearing, Fletcher (a book), D. Van Nostrand.
11. The Noise Primer, General Radio Co.

The Liquid Rheostat Returns!

ALLAN HALTER
Electric Control Section
Allis-Chalmers Mfg. Co.

★

Water is cheap—and holds a lot of heat! With a new design, the historic liquid rheostat renews its lease on life.



LIQUID RHEOSTAT for speed control of a 350 hp wound rotor motor is being assembled and awaits installation of control wiring. (FIG. 1)

WITH larger and larger amounts of power employed by industry, controls must become correspondingly more accurate. Ordinarily we expect progress to come from new methods and schemes and it seems paradoxical that engineers concerned with control problems should be returning to one of the earliest and probably the simplest type of control devices. Yet, this is what is happening with the return of the liquid rheostat into control schemes.

In general, liquid rheostats, which use water for the resisting medium, have the following advantages:

1. They are safe and inexpensive.
2. They are compact and simple with only a few parts, usually a container, an electrolyte, electrodes, and some mechanism for lifting the electrodes.
3. There are no metallic contacts to be destroyed by arcs.
4. They offer a continuous resistance change with no taps or steps.

Disadvantages inherent in earlier liquid rheostats, but recently overcome, have been:

1. Inability to give desired resistance range without making unit large and cumbersome.
2. Inability to achieve "straight line" speed characteristic.
3. Flashover between electrodes too closely spaced in air.

There are three applications in which the liquid rheostat has shown its merit, namely; absorption of load, motor starting and speed control. It is the last of these applications that has been the most difficult to meet, because of both the necessary heat dissipation and the wide range of resistance required.

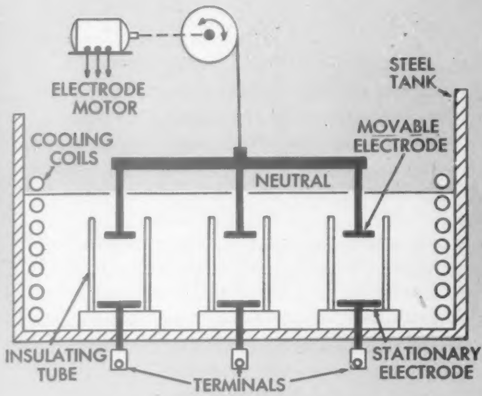
Speed control may be one of two types. In the first type, the speed is automatically reduced when heavy intermittent loads, such as occur in blooming mills, are applied to a flywheel m-g set by limiting the input to the induction motor, and allowing the flywheel to provide the additional energy for the peak loads. In this way, the motor size and power equipment can be kept to a minimum. Or, speed control may be of the type where the speed must be accurately controlled at all times, as in blowers, pumps, fans, and special mechanical drives.

Stepless speed control of an a-c motor can be obtained by any one of the following methods:

1. Special form of variable speed a-c motor.
2. Use of d-c motor-generator power supply.
3. Hydraulic coupling.
4. Magnetic coupling.
5. Standard slip ring motor and liquid rheostat.

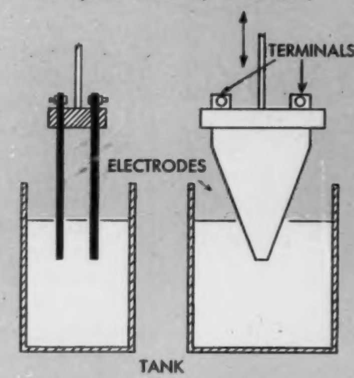
In general, the first two methods are costly and complex, because of the special additional machines required. Consequently, variable speeds are most often obtained from a standard squirrel cage or synchronous motor with hydraulic or magnetic coupling, or by a slip ring motor.

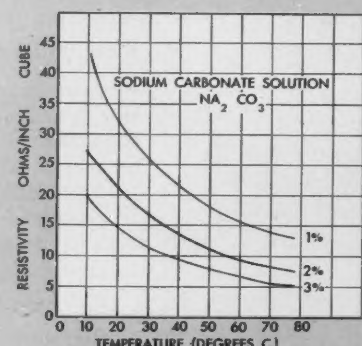
Operating characteristics of the last three are very similar. The efficiency of the liquid rheostat is slightly better than that of the coupling control. Both the driving motors for use with the couplings or with the rheostat are reliable pieces of equipment and seldom cause trouble. The couplings, however,



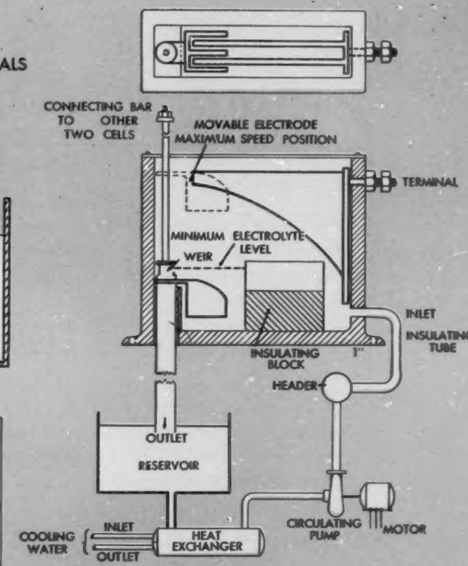
BASIC ELEMENTS in a simple three-phase water rheostat are shown above. Because electrode area must be large for minimum resistance at full speed points, length of travel must be great. **(FIGURE 2)**

ANOTHER ARRANGEMENT of electrodes in a simple resistance cell allows better control of resistance taper. Vapors rising from the solution, however, may lead to flashover between exposed electrodes. **(FIGURE 4)**





RESISTIVITY of various sodium carbonate solutions in average tap water are shown. The curve for water is not shown because of wide water supply variations. **(FIGURE 3)**



"IDEAL" rheostat which prevents flashover between electrodes and achieves desired characteristics is approached in new design. One cell is shown above. **(FIG. 5)**

are complex mechanisms and may cause occasional trouble. Since the liquid rheostat is simple, it is reasonable to expect less maintenance expense. It also requires less floor space.

Methods of varying resistance

As previously stated, the liquid rheostat consists mainly of a container, an electrolyte, the electrodes, and a means of varying the resistance as in Figure 2. The resistance of the electrolyte can be treated as a metallic conductor with a negative temperature coefficient as $R = \frac{C\,L}{A}$, in which R = circuit resistance, C = specific resistivity of the liquid, L = length of paths between electrodes, and A = area of conductivity path.

This equation is not true for direct current, or for alternating current of less than two cycles because of gas formation on the electrodes, which acts as an insulator. In general, the resistivity of tap water is too high except for large machines with high voltage secondaries. For the average low voltage secondary motor some salt or acid solution is used to increase the conductivity of the electrolyte. Sodium carbonate (Na_2CO_3) has been found to be the most practical to use in the solution as it is non-corrosive and relatively cheap. How the resistivity of sodium carbonate varies with the temperature and saturation of the solution is shown in Figure 3. The degree of saturation is given in percent of weight of water. When the solution is increased above 3 percent the conductivity is increased only slightly, making it uneconomical to use a more concentrated solution.

From the resistance equation given above it can be seen that the resistance can be varied by two methods. The first method employs changing the distance between stationary and movable electrodes. The second effects resistance control by changing the area of solution between relatively stationary electrodes. Both methods have been used in regulators, depending upon which is best suited for the particular application.

Figure 2 shows three cells of a regulator which varies the resistance by changing the distance between electrodes. Usually these cells, consisting of an insulated base and an insulating tube, are mounted in a steel tank which contains the electrolyte and cooling coils. The movable upper electrodes are tied together both mechanically and electrically.

Disadvantages of this type of regulator are twofold: first, the three phases cannot be too closely located because of the electrical leakage between the stationary electrodes, which are very difficult to insulate, and secondly, the resistance is a straight line function of rheostat position, whereas most speed control applications are of the variable torque type giving unequal speed changes per unit distance of electrode travel. Also, because a definite area is required to carry the full load current at full load (about 1/16 inch electrode spacing), a wide range of speed control means a very long travel of the electrode, giving excessive height to the rheostat.

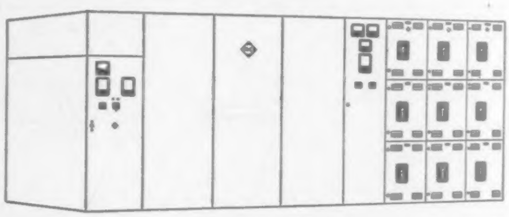
Some of the later installations of this type have three separate insulated tanks with a common external heat exchanger, overcoming the insulation problem with the cells mounted to save space. With an external heat exchanger a circulating pump is used, and the cold electrolyte is guided directly between the electrodes to give more efficient heat dissipation.

New Products

Unit Substations Are Completely Standardized

Reduced installation time, saved floor space and modern, attractive appearance are features of new unit substations which have been completely standardized. This standardization makes all dimension information essential for construction available on request.

Switchgear and new dry-type transformers have been so designed that the component parts present a unified substation, unbroken along its entire length, depth, and height. Simplified internal switchgear construction eliminates conventional throat connection to transformer and allows flexibility of application.



New Safety Panel Protects Welders

A new voltage control panel which automatically reduces the voltage of a-c welders from 75 volts to 25 volts during open circuit is announced. Primary advantages of this unit are protection of the weldor from shock when working under adverse conditions like moisture, limited space and inexperience, instantaneous voltage recovery when arc is struck, reduction of welder idling losses, and protection against short circuits.

These new control panels, produced in two models, can be externally mounted on all manually operated a-c welders, particularly the "Ampac" 200 and 400 units.

X5 Electrode Welds Many Castings Without Preheating

Characterized by an unusually stable arc, a new nickel cast iron electrode, the X5, permits welding of many foundry castings without preheating. It functions equally well on alternating or direct current. When using d-c, reverse polarity gives better results.

The X5 electrode meets all requirements for color-matching, and eliminates trapped slag and gas pockets. Castings that are heavy, highly stressed or requiring accurate machining are best welded by preheating to 600 F. Oil-impregnated castings should be preheated to about 700 F to ensure deposits of clean, machinable weld metal.

———o———

MORE FACTS about these new products are available on request. Write the Allis-Chalmers ELECTRICAL REVIEW, Allis-Chalmers, Milwaukee 1, Wisconsin.

Figure 4 illustrates a cell in which the distance between electrodes remains fixed and the area between is varied by raising and lowering the electrodes, or by controlling the height of the electrolyte with a weir or gate. With this arrangement the electrodes can be so shaped to suit any particular application as to give a more linear "speed" versus "electrode position" curve, thus overcoming one of the main disadvantages of the type of regulator shown in Figure 2. Offsetting this advantage, however, is the problem of insulation between the two electrodes. As can readily be seen, in order to keep the electrodes and cell down to a reasonable size, the electrodes must be quite close together. During operation the vapors rising between the electrodes lowers the air dielectric strength and at times may possibly cause arcing and flashover between the electrodes.

New rheostat approaches ideal

It becomes apparent that the ideal rheostat is one which would keep the electrodes below the liquid to prevent flashover and, in addition, be able to so regulate the length and area of the current path between electrodes that the desired "speed" versus "rheostat position" characteristics will be obtained. Such an arrangement is very nearly approached by a new liquid slip regulator design illustrated in Figure 1, one cell of which is shown in Figure 5.

The construction is as follows:

The container, or cell, of insulating material is made long and narrow. On one end is mounted the stationary electrode, which extends nearly the full length of the container at the top, and slopes back to the supporting end near the bottom. One the other end of the cell is a movable weir to which is fastened a smaller electrode slightly below the level of the weir. Mounted on the bottom of the cell between the two electrodes is an insulating block. Three such cells are mounted side by side with their weirs connected to a common lifting mechanism. This connection also serves as an electrical connector between the three movable electrodes, forming the neutral. Inlets are on the same end as the stationary electrode, and are connected to a common header by means of insulating tubes. A reservoir, heat exchanger, circulating pump, and lifting mechanism for the weirs make the unit complete.

In operation, the electrolyte enters the cell through the insulating tube. After it has filled the cell to the level of the weir, it continues to discharge into the reservoir directly beneath the cell. From the reservoir it passes into a heat exchanger, through the pump, and back into the header, to repeat the cycle. With the weir in its lowest position, the length of the current path through the electrolyte is the longest, giving maximum resistance. When the weir is raised, as in Figure 6, the liquid level will also rise, always keeping the neutral electrode covered, and the length of conducting path will be gradually decreased, until the electrodes inter-mesh at the upper limit to give minimum resistance.

In addition to a decreasing length of path, the area of current carrying electrolyte is increased and by proper design of the stationary electrode and insulating block almost any type of "resistance" versus "position" curve can be obtained to give equal speed changes per unit rheostat travel. The movable electrode is prevented from rising faster than the electrolyte

by setting the speed of the electrodes' control element equal to or slower than the rate at which electrolyte enters the cell.

In passing through the electrolyte the current causes heating. The warmest liquid will rise to the surface, and as the general flow of electrolyte is from the inlet side to the weir, it will be carried out into the reservoir and then through the heat exchanger to give up its heat. Because the flow is parallel with the electrode plates, there is a free flow over the entire surface, preventing local hot spots near the electrode plates. The upper corner of the movable electrode is rounded off in order to keep the current from concentrating on it when near the stationary electrode.

An analysis of a typical problem shows how such a liquid rheostat is well-adapted to motor speed control. Assume that a 350 hp, 720 rpm (synchronous speed) fan motor is to be varied from 30 to 90 percent synchronous speed. Secondary voltage on the blocked wound rotor is 750 volts and full load rotor current is 210 amperes. The fan load curve for such an installation is shown in Figure 7.

In an induction motor the following equation applies:

$$\text{Total rotor circuit loss in kw} = \frac{(\text{kw shaft output} + \text{kw friction and windage}) \times \%\ \text{slip}}{1 - \%\ \text{slip}}$$

Neglecting the friction and windage losses, which are quite small as compared to the shaft output, we can find the total rotor circuit losses. Curve B of Figure 7 shows these losses for the desired speed range. Inasmuch as the induced voltage of the rotor is a direct function of percent slip we can calculate the secondary current curve C by the following equation:

$$I_s = \frac{\text{kw rotor loss} \times 1{,}000}{E_i \times \sqrt{3}}$$

E_i being the induced secondary voltage.

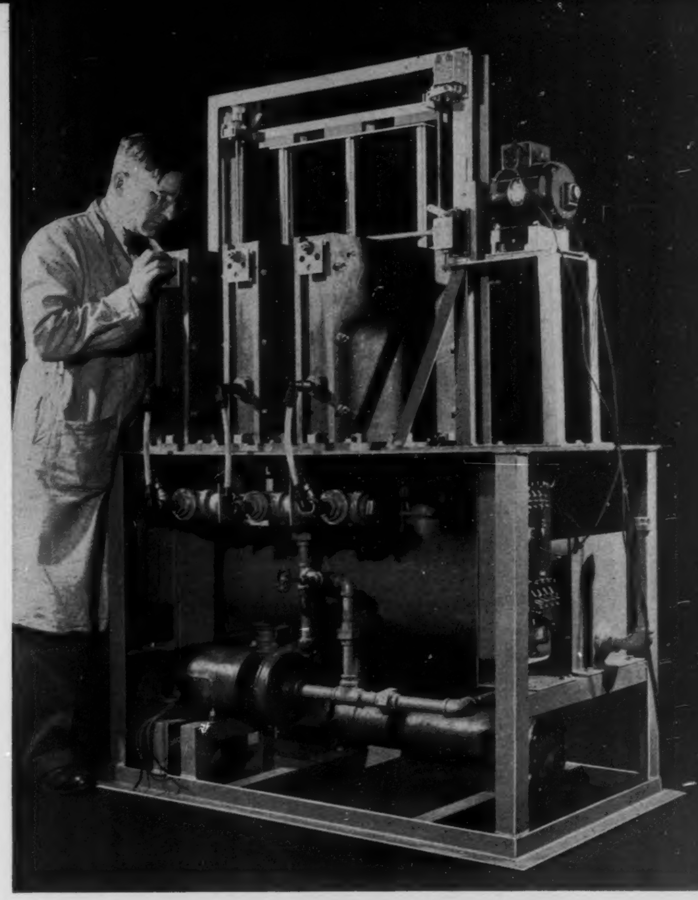
The terminal voltage of the machine is then the induced voltage minus the IR drop of the machine. In this case the resistance is .036 ohms per phase at 75 degrees C. Knowing the terminal voltage and the current per phase we can then find the required cell resistance Curve D by the equation:

$$R\ (\text{per cell}) = \frac{E_i}{\sqrt{3} \times I_s}$$

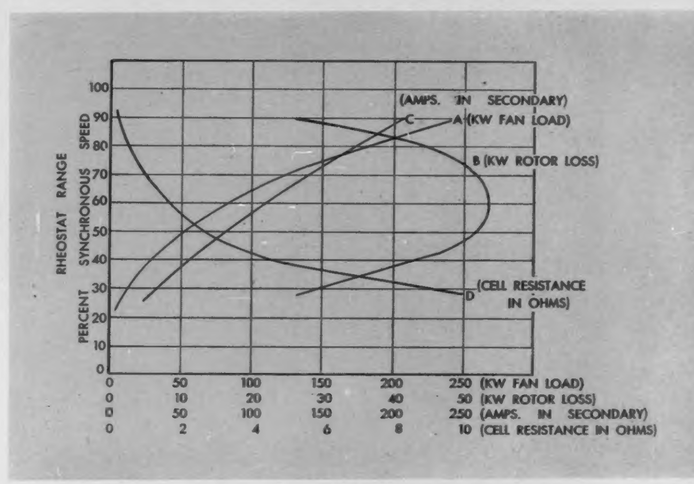
The resistance of the cells is obviously far from a linear function of speed, and if it is desired to have equal speed changes per unit rheostat travel, there must be a change in area in addition to the change in length of the current path through the electrolyte. By variations of the cross-section of the insulating block this area can be quite easily controlled, working from the data shown in Curves C and D in Figure 7.

Using this arrangement, a "straight line" speed characteristic is achieved which could not be obtained with the regulator illustrated in Figure 3, while insulating qualities are retained superior to those of Figure 4. One electrode is always submerged and the three stationary electrodes are enclosed in separate insulating tanks.

Variations of the resistance can be as gradual as required over a large range while the unit is kept small and compact. Liquid slip rheostats are again featured in control schemes where a simple, economical, and reliable piece of equipment is required.

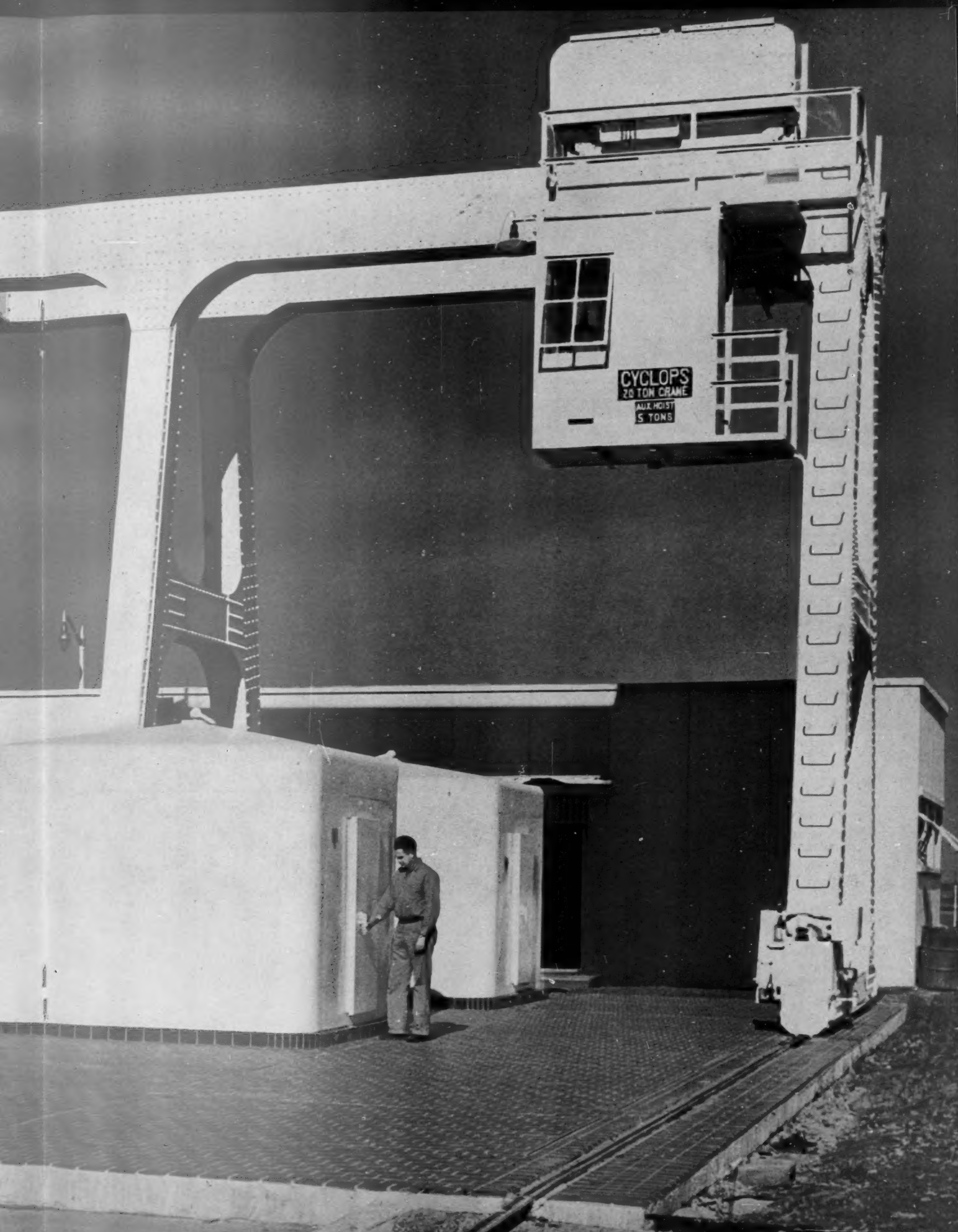


WEIR AND MOVABLE ELECTRODE ASSEMBLY is at the top of its travel in a liquid rheostat, shown above, under test. Parallel screws maintain uniform travel between top and bottom limit switches. **(FIGURE 6)**



REQUIRED SLIP RESISTANCE varies considerably from the linear function of speed of a fan load application. Proper design of external rotor resistance provides accurate wide range speed control. **(FIGURE 7)**

NINETY-FIVE MILLION gallons of water a day are handled by this modern outdoor west coast pumping station. Two 4,000 hp, 900 rpm vertical shaft motors are housed in the streamlined buildings, center. Switchgear, too, in the cubicles at the left is designed for outdoor installation.


CYCLOPS
20 TON CRANE
AUX. HOIST
5 TONS

A *Survey* of Modern Motor Starters

JOHN BAUDE
Switchgear Section
Allis-Chalmers Mfg. Co.

Much-needed information on the characteristics of standard motor starters one to 10,000 hp is condensed here.

MOTOR control today represents a major application for all types of switchgear and circuit breaker equipment. And while motor control requires the same basic protective and switching devices as standard power feeders, ratings of similar equipment are not always parallel.

Circuit protection for motors must allow for starting transients and load fluctuations, but at the same time it must protect against cumulative heating which could result from sustained minor overloads, or from single phasing.

A degree of standardization has been achieved in motor starters, particularly for motors of smaller sizes. For really large motors, each application represents an individual problem because here supply system limitations enter into the picture more prominently. However, in the great majority of motor applications, standard starters or starters assembled from various standardized switching and protective devices can be used.

Data concerning standard motor starters has been compiled in Figure 1 showing these starters charted with reference to interrupting capacity, hp rating and voltage range. For the purpose of clarity, the various starters have been combined arbitrarily into five groups and designated A, B, C, D, and E (momentarily disregarding NEMA classifications 1C2-128 for non-ventilating enclosures and 1C2-129 for ventilated enclosures).

Different types of starters can often be employed for a single application. This condition is demonstrated in Figure 1 by the overlapping areas representing distinctly different types of equipment. In reality, only one type of motor starter will be the most suitable for service in each case, and in order to make the proper selection basic knowledge of standard equipment is indispensable. Selection of the proper equipment must consider safety of operators or workers in the neighborhood of the equipment when installed; cleanliness and moisture conditions; effect of maintenance or inadvertent shutdowns; switching frequency; effect of plant expansion on usability of equipment; effect of normal operation on other plant services; future salvage value of the equipment; as well as economic justification of the installation.

A short description of each of the five types of starters follows and the important features of each type of motor starting equipment are summarized.

A — metal-clad vertical lift switchgear

Vertical lift switchgear is suitable for a wide range of applications, covering all standard voltages from 2,200 to 15,000 volts at interrupting capacities from 50,000 to 500,000 kva. This type of equipment is represented by area A in Figure 1. The most important features of this class of equipment are that breakers may be selected with interrupting capacity equal to the requirements of any system, regardless of its size; maintenance may be performed with minimum outage time, and motor starting equipment may be lined up with other power distribution switchgear equipment to provide a neat, uniform-appearing installation.

All live parts of the switchgear assembly are fully enclosed and insulated. The circuit breakers can be removed for inspection and are interchangeable with spare breakers with minimum loss of time. The equipment leaves the manufacturer completely wired to conveniently located terminal blocks ready for connection to the power circuits.

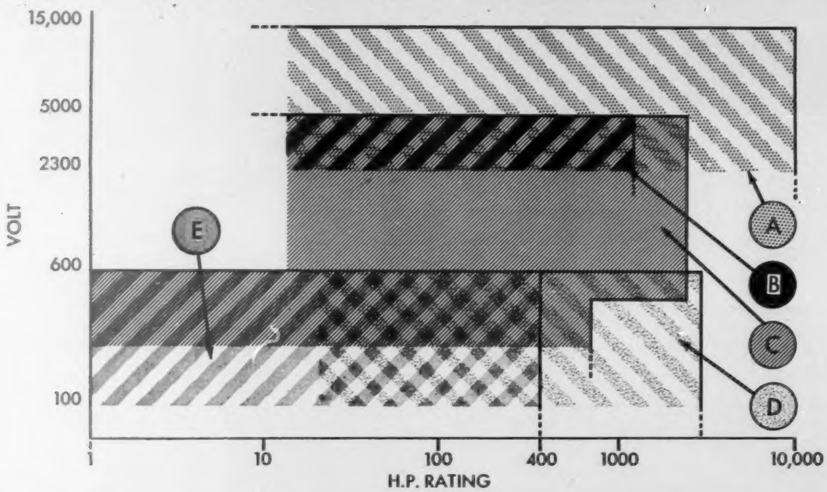
This type of motor starting equipment is available for outdoor or indoor installation and with oil, air, or airblast circuit breakers. Various circuit arrangements can be built by the proper combinations of standard units and parts.

The sturdy construction and inherent safety built into metal-clad vertical lift starting control is shown in Figure 2. No high voltage terminals are exposed and inspection and repairs can be made in complete safety.

In Figures 3 and 4 is shown 50,00 kva interrupting capacity circuit breaker equipment suitable for operation in the tropics for starting 500 hp, 2,300 volt, 25 cycle induction motors. The integral parts of this motor starter are mostly of standard design, yet individual requirements have been fully satisfied in an economical way by properly employing the inherent versatility of vertical lift switchgear equipment.

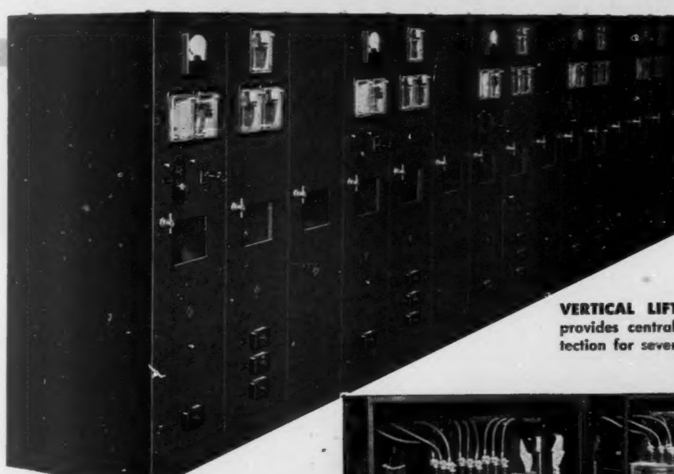
Basically the same starting equipment as shown in Figures 3 and 4 can be used for synchronous motor control with the addition of field application equipment. In this case an

LIMITS AND RATINGS of the various types of standard motor starting equipment used today are presented here. Although both the upper and lower limits of application may vary slightly from the points shown, these values are representative of the best switchgear and control engineering practice. **(FIGURE 1)**

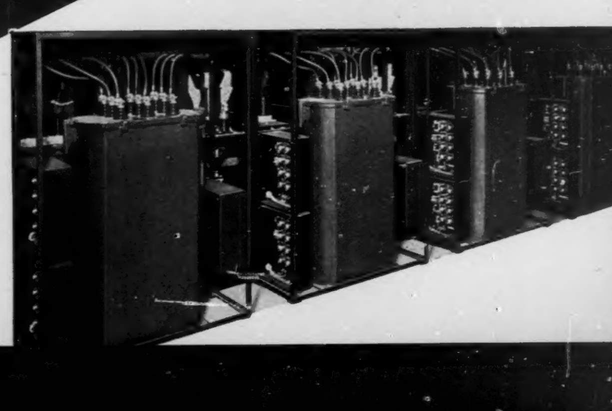


Maximum HP Rating	Voltage Range	Type, Interrupting Capacity, Designation of Standard Motor Starters	
10,000	2,200 to 15,000	"A"	METAL CLAD VERTICAL LIFT SWITCHGEAR 50,000 TO 500,000 KVA INTERRUPTING CAPACITY
3,000	110 to 600	"B"	LOW VOLTAGE METAL CLAD SWITCHGEAR 15,000 TO 100,000 AMP. INTERRUPTING CAPACITY
1,250	2,000 to 5,000	"C"	FUSED METAL-ENCLOSED MOTOR STARTER 150,000 TO 250,000 KVA INTERRUPTING CAPACITY
2,500	220 to 5,000	"D"	OPEN OR ENCLOSED MOTOR CONTROLLER (INTERRUPTING CAPACITY 10 TIMES MOTOR FULL LOAD CURRENT)
1,000	220 to 4,500		
2,500	220 to 5,000		
400	110 to 600	"E"	GENERAL PURPOSE STARTER OR COMBINATION MOTOR CONTROL

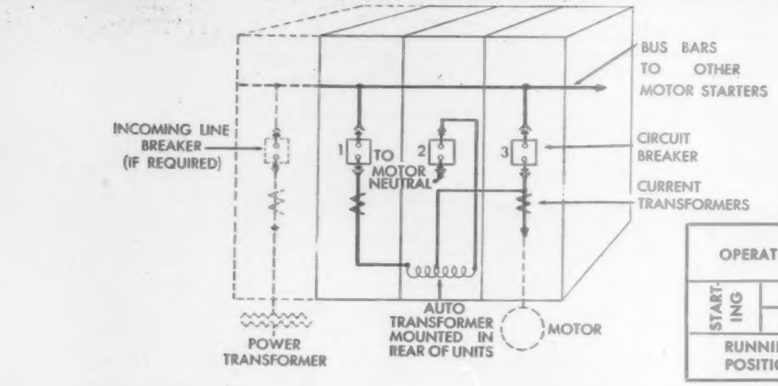
A 50,000 KVA magnetic air breaker is being rolled into position following routine inspection. Entire dolly can be hoisted with a crank-operated lift screw with high voltage and control connections made automatically during lifting. **(FIGURE 2)**



VERTICAL LIFT SWITCHGEAR lineup (left) provides centralized starting control and protection for several 500 hp motors. **(FIGURE 3)**

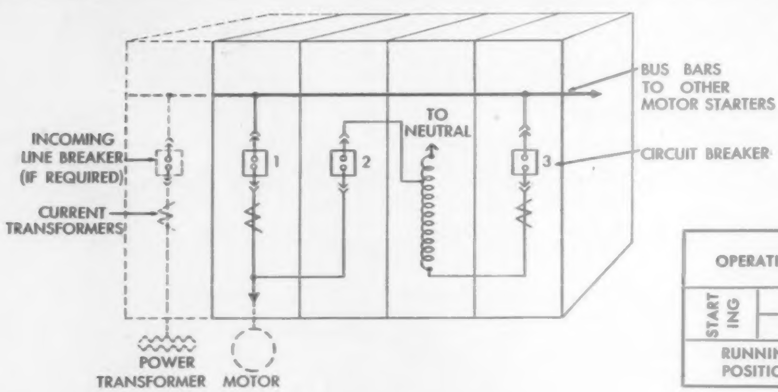


REAR VIEW of part of metal-clad gear in Figure 3 shows 25-cycle starting auto transformer mountings. Dry disc rectifiers provide d-c for breaker operation. **(FIGURE 4)**



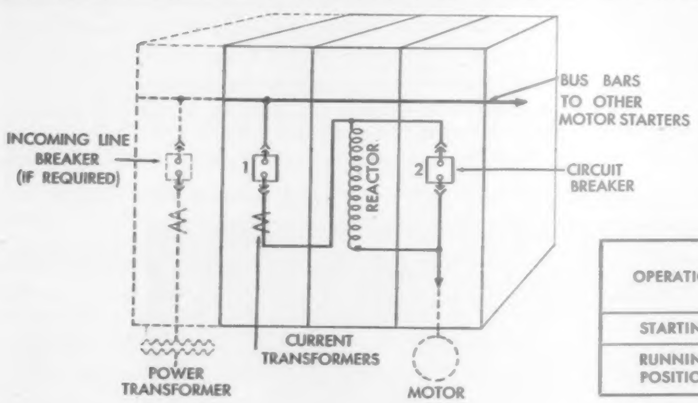
SINGLE LINE diagram of typical connections using the closed circuit method of starting with auto transformers. **(FIG. 5)**

OPERATION		BREAKER		
		NO. 1	NO. 2	NO. 3
STARTING	1	CLOSED	CLOSÉD	OPEN
	2	CLOSED	CLOSED	CLOSED
RUNNING POSITION		OPEN	OPEN	CLOSED



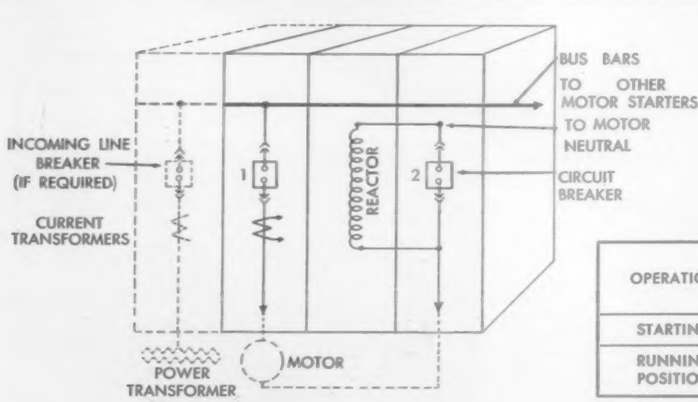
SINGLE LINE diagram of typical connections using the open method of starting with auto transformers. **(FIGURE 6)**

OPERATION		BREAKER		
		NO. 1	NO. 2	NO. 3
STARTING	1	OPEN	CLOSED	CLOSED
	2	OPEN	OPEN	OPEN
RUNNING POSITION		CLOSED	OPEN	OPEN



LINE DIAGRAM uses reactors in series with the line for reduced voltage starting of induction, synchronous motors. **(FIG. 7)**

OPERATION	BREAKER	
	NO. 1	NO. 2
STARTING	CLOSED	OPEN
RUNNING POSITION	CLOSED	CLOSED

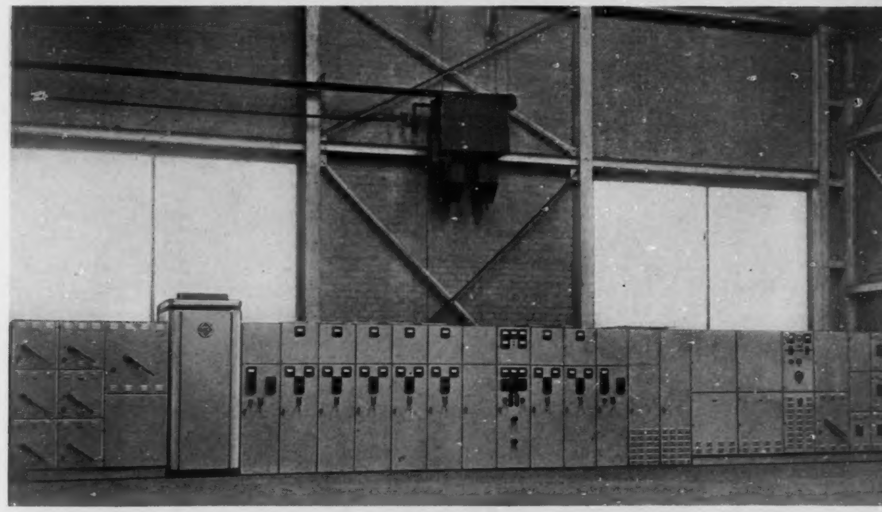


LINE DIAGRAM using reactors in series with the lines to neutral for reduced voltage motor starting. **(FIGURE 8)**

OPERATION	BREAKER	
	NO. 1	NO. 2
STARTING	CLOSED	OPEN
RUNNING POSITION	CLOSED	CLOSED

LOW VOLTAGE DRAWOUT type air breaker case, side panel removed, shows three 600 amp, 600 volt starters in withdrawn, test, and operating positions. **(FIGURE 9)**

LOW VOLTAGE MOTOR CONTROL CUBICLES like those at the left together with high-voltage switchgear, transformer, and rectifier d-c supply form a neat appearing, efficient load center substation in a large steel plant. **(FIGURE 10)**



automatic field switch is energized by an auxiliary field application relay sensitive to motor speed.

Two of the most common methods utilizing auto-transformers and breakers for reduced voltage motor control are shown in Figures 5 and 6. Figure 6 shows the use of an auto-transformer in connection with three breakers in the "open circuit" method of starting. This scheme differs from one shown in Figure 5 in that during the starting period the motor is completely disconnected from the line for a moment during switching operations. This condition may be objectionable in cases where the motor has to start with considerable load. In general, however, careful analysis shows that the loss of speed during momentary switching operations can often be neglected. Figure 6 offers the possibility of using one auto-transformer to start several motors consecutively.

In the case of reactor starting, various connecting schemes are possible. All schemes use a reactor for reducing the voltage at the motor terminals during the starting period. The reactor is short-circuited or entirely disconnected from the line after the motor is running. Reactor starting schemes commonly used and employing two circuit breakers are shown in Figures 7 and 8. In the case of the connection as shown in Figure 7, both breakers must have the same interrupting capacity. With the circuit of Figure 8, it is sometimes possible to use a short-circuiting breaker having a somewhat lower interrupting capacity than the running breaker. In the second method, however, two cables must be laid connecting the motor to the switchgear equipment.

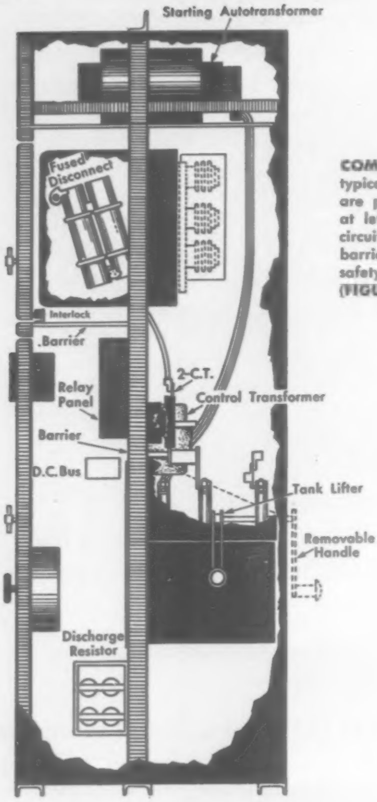
B — 600 volt horizontal drawout switchgear

This type of metal-clad switchgear is designated on Figure 2 by the area B. Interrupting capacities from 15,000 amperes to 100,000 amperes are standard. It provides in general the same basic features as vertical lift switchgear (designated by area A) for the lower voltage field and can be used in the same starting schemes as described previously for vertical lift switchgear. All units of this type are factory wired and assembled.

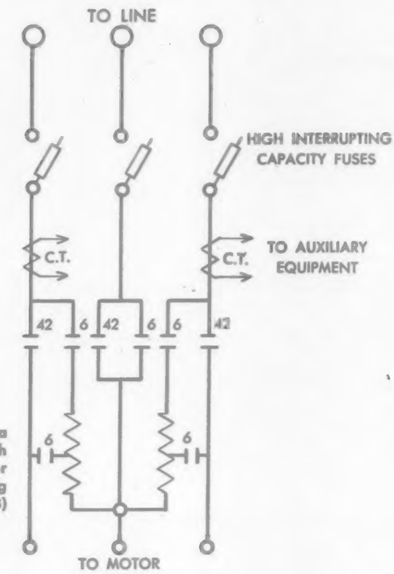
The manner in which each individual breaker can be drawn from its operating position for inspection or maintenance purposes is shown in Figure 9. Instruments, control switches, and relays can be mounted on a separate panel, and the unit which carries the instrument panel can be arranged in many cases to house the starting auto-transformer or reactor.

Metal enclosed motor control equipment of the types designated as B are frequently connected through throats to transformers forming load center unit substations. Figure 10 shows a typical arrangement where air-cooled transformer cubicles form part of the switchgear lineup.

FUSED STARTERS offer economies in motor and line protection in medium size installations. Control with door open is electrically operated from a remote position, hence no manual equipment on the panel. Test and inspection connections are provided. **(FIG. 11)**



COMPONENTS in a typical fused starter are placed as shown at left. High voltage circuits are behind barriers or doors with safety interlock. **(FIGURE 12)**



LINE DIAGRAM of a fused motor control with transformer connection for reduced voltage starting is at right. **(FIGURE 13)**

	CONTACTS NO. 6	CONTACTS NO. 42
OFF	OPEN	OPEN
START	CLOSE	OPEN
RUN	OPEN	CLOSE

C — fused motor starters

Designated by area C, in Figure 2, these metal-enclosed motor starters consist of a sheet metal housing in which is mounted a set of high interrupting capacity disconnecting type current limiting fuses, heavy duty oil or air contactors, and all necessary protective circuit elements such as overload relays, etc. The current limiting fuses give short circuit protection to each motor as well as to the starter and line. The fuses are silent, dry, emit no gas or flame, and provide indication when they blow. They clear all faults which are equal to or greater than the interrupting rating of the starting contactor, which is used for all normal switching operations. The swinging type front panel normally carries all required instruments and control switches.

A group of motor starters for automatic full voltage starting of Squirrel Cage Induction Motors is shown in Figure 11 and a typical cross section and simplified line diagram of this equipment in Figures 12 and 13.

Fused metal-enclosed motor starters offer a method of obtaining protection and starting control for large motors with a minimum of investment. They are highly standardized for all induction and synchronous motor starting schemes, such as full voltage starting, reduced voltage, reactor starting, part winding starting, two speed control, plugging, reversing, and dynamic braking.

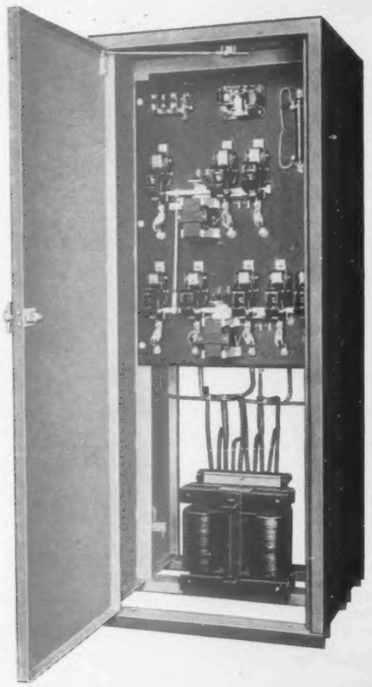
D — open or enclosed panel motor controller

The wide range of standard open or NEMA type 1 enclosed starters in this class is illustrated in Figure 1, area D. The interrupting rating of this control is ten times motor full-load current, and standard contactors are utilized in all cases. Figure 14 shows the design of one of these starters, which are built with or without enclosures. In the enclosed version all live parts are well protected. The starting and protective relays are mounted where necessary inside of the enclosure or on the front panel. The low cost of this equipment makes this design attractive in cases where heavy fault currents may not be expected, or where back-up circuit breakers operating in connection with these starters offer suitable protection. Figure 15 shows a typical line diagram.

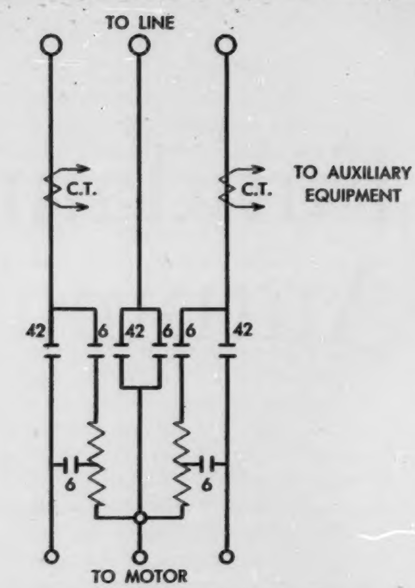
E — general purpose starter or control

The last in the series of standard motor starters covers the wide application range illustrated in Figure 1, area E. These starters or reversing motor controls are normally considered stock items by control manufacturers. A wide variety of enclosures from water-tight to explosion-proof are standard. Fuses, disconnects, auto-transformers, reset mechanisms and breakers can be combined in a large number of ways to provide motor starting control at low cost. A typical wall mounted starter and line diagram is shown in Figures 16 and 17.

Figure 1 shows clearly how some motor sizes can be installed with as many as three different types of starting control. To choose the best one for any given installation requires that consideration be given to all factors affecting control selection. Economy in first cost may be offset by lower re-use value following load growth. Versatility may be of more value than small space requirements. Operator safety, maintenance costs and installation expense must all be weighed in choosing motor control that will provide the most in dependability, safety, and economy.

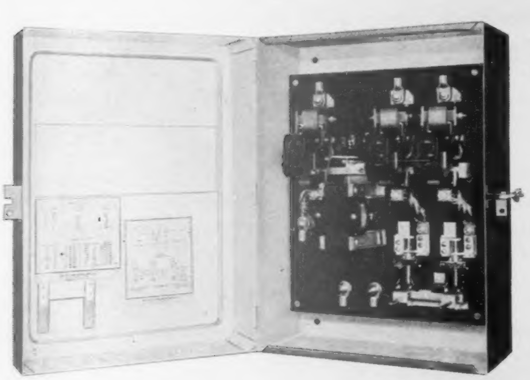


METAL ENCLOSED STARTERS can be applied to various motor sizes. These reduced-voltage autotransformer type starters will handle a 125 hp, 440 volt motor. Where dust and personnel safety are not factors, metal enclosures are omitted. **(FIGURE 14)**

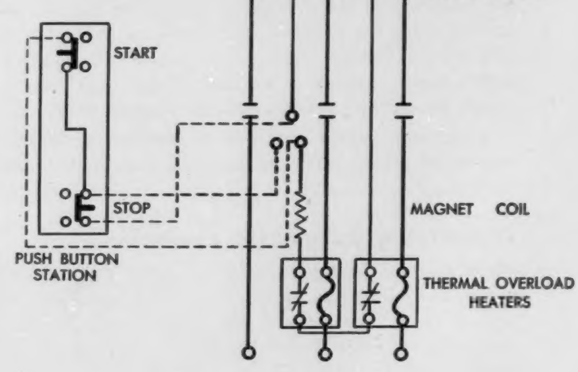


	CONTACTS NO. 6	CONTACTS NO. 42
OFF	OPEN	OPEN
START	CLOSE	OPEN
RUN	OPEN	CLOSE

LINE DIAGRAM of contactor at the left is similar to that of Figure 13 except for fuses. Contactors are used here in place of the oil breakers in Figures 11 and 12. **(FIGURE 15)**



OVERLOAD PROTECTION for this wall-mounted motor starter with NEMA type 1 (general purpose) enclosure for a 25 hp, 440 volt motor is provided by thermal relays in the lower right hand corner. Fuses are required for line protection. **(FIG. 16)**



LINE DIAGRAM of starter at the left shows push button and relay contacts in magnet coil circuit. A single starter can be adapted to a wide range of motor sizes by simply changing heater strips in the overload relays. **(FIGURE 17)**

Fundamentals of Automatic Controls

PART ONE OF TWO PARTS

WALTHER RICHTER
Engineering-Development Division
Allis-Chalmers Mfg. Co.

Certain fundamental relations must be considered if satisfactory operation of any automatic control is desired.

MODERN LIFE without the benefit of automatic control can hardly be visualized. It enters our daily lives directly or indirectly to a degree which would have seemed fantastic a few decades ago. Automatic control of the temperature of the home, the flat iron, the toaster, etc., are taken for granted, as is automatic volume control in our radio. The Power company furnishing electric power to our homes not only regulates the voltage automatically, but also the frequency of the alternating current, so that we seldom have to adjust our electric clocks. These are only a few examples of direct contact with automatic control; our indirect contact, however, exceeds by far that of the direct contact. It is safe to say that practically every product of industry, be it a piece of writing paper or an automobile, has, in the process of its manufacture, had the benefit of automatic control.

Classifying automatic controls

Many attempts have been made to evolve an all-embracing system of classification by means of which any given control scheme could be analyzed. But it seems that as soon as a system has been developed providing a pigeonhole for each type of control, somebody comes along with another type of control, which either does not fit any one of the classifications provided or fits into several of them simultaneously. The field is simply too big for a breakdown into sharply defined categories and there will therefore always be overlapping of some of them, as well as inability to place a given control in its proper category.

The elementary discussion offered here is not meant to be a presentation of automatic control theory in three easy lessons, which in the light of the remarks made in the preceding paragraph would be quite impossible, but rather to call attention to some fundamental relations which must be taken into account if satisfactory operation of a given control is expected. We shall confine ourselves here to a discussion of controls whose purpose is to hold a given quantity at a constant value.

Common sense tells us that, if any quantity changes, there must be one or several influences at work which cause this change. The speed of a d-c or induction motor, for instance, will be influenced by a change of load or by a change of applied voltage; in the case of the d-c motor, the excitation of the field winding is an additional factor influencing its speed. It is apparent that an automatic control simply plays these influences against each other, for the purpose of keeping the controlled quantity at the desired value. To be more specific, it counteracts the effects of the factors over which we have no control by bringing into play the factors over which we do have control.

At this point it may be desirable to explain the difference between an open and a closed cycle control. In an open cycle control, the quantity to be controlled is, in a certain sense, actually ignored; the control simply adjusts the controllable factors in a certain relation to the uncontrollable factors; the proper relation must be known either by experiment or by calculation. The voltage of a d-c generator—provided its speed and shunt field excitation is held constant—will depend on the load current which it has to furnish. If the relation between these quantities is known, either by experiment or by calculation, it is an easy matter to provide a compound winding which furnishes additional excitation with an increase in load current. This is therefore an open cycle control for the generator voltage; there is no device observing the quantity to be controlled, but it is held constant within limits by adjusting the controllable factor, in this case the excitation in the compound winding, to a value proportional to the load current which the generator has to furnish.

No one would give serious consideration to an open cycle control for the temperature of a home, but it would have to work in the following way: an outdoor thermometer and perhaps an instrument measuring the strength of the wind would be made to act on the draft control of the furnace, adjusting the latter to a certain value for given outdoor conditions. It is easy to see that such a control would be quite unsatisfac-

tory, since it is entirely impractical to take into account all of the uncontrollable factors determining the temperature in the house, such as the opening of a window, for instance. It might be of interest, however, to note that some of the electrically heated blankets which appeared on the market just before the war employed a temperature control of the open cycle type; the thermostat controlling the amount of current through the blanket responded to room temperature rather than to the temperature of the blanket itself.

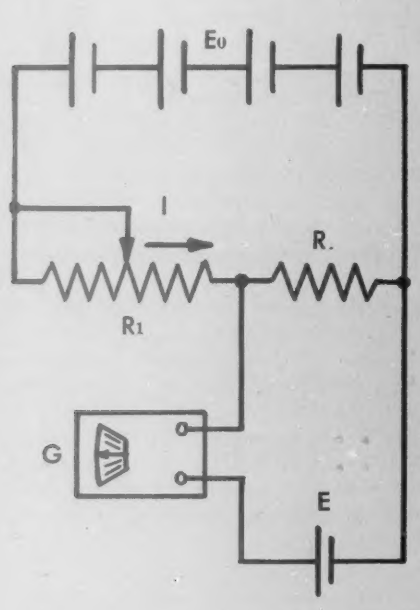
Open cycle controls are characterized by the absence of any device observing the quantity to be controlled; they are usually simpler than the closed cycle control but are seldom as accurate. One advantage possessed by them is that the troublesome problem of hunting is practically non-existent because no closed chain exists between the quantity to be controlled and the factors exercising regulation of it.

Closed cycle controls more common

Our further discussions will concern themselves only with the closed cycle type of control. The reason for using such a designation is perhaps best explained by quoting from a recent article by Prinz:[1]

"In an automatically controlled process, a deviation of the variable to be controlled (temperature, voltage pressure, frequency, speed, etc.) from the rated value will influence another variable (e.g. voltage of a thermocouple, position of an instrument pointer, rheostat slider or valve) which in turn influences a third variable acting on a fourth variable and so on. The last of these variables acts finally on the initial variable in such a manner that it is forced back to the rated value, or as near to it as the controlled mechanism will permit.

"Thus the controller may be described by a closed chain of variables, each of which influences the following and is influenced by the preceding one."



SENSITIVITY AND ACCURACY are often confused. The relationship between the two in this simple circuit is explained in the article. **(FIGURE 1)**

Applying this thought to the analysis of our home heating plant, we have the room temperature which is to be held constant and which acts on the thermostat on the wall; the thermostat closes a control relay, which in turn makes the motor of the oil burner or stoker run; more heat is supplied to the room, and the control cycle is closed by the action of the temperature rise on the thermostat. Note that in contrast to the open cycle control the uncontrollable factors are completely ignored, i.e., there are no instruments observing the outdoor temperature or the wind velocity, etc. This, then, is a more appropriate and direct approach to our problem, because the control pays attention only to the quantity in which we are really interested.

Comparing automatic and manual control

When contemplating the design of any automatic control it is always a good plan to ask what instructions we would have to give an operator if the control were to be accomplished manually. To be sure, for many control processes we would have to visualize an idealized operator whose response would be much faster than any human being could act, but apart from this difference we must not ask our automatic control to do something for which we could not give explicit instructions to an operator! As a matter of fact, the notion that an automatic control is always superior to a manual control is quite erroneous; E. J. Rhodes, on page 423 of his book, "Industrial Instruments for Measurement and Control," makes the following statement:

"Where a choice can be made between automatic control and manual control solely on the basis of the method that will achieve the more accurate control, the following rules will apply:

"1. If the changes are rapid and repetitive, automatic control will give the better results.

"2. Where there is time to make adjustment manually, intelligent human control will be superior to any form of automatic control."

The reason for the truth of the second rule is that intelligent human control can take into account experience obtained from previous control operations which an automatic control cannot do. A person familiar with a coal fired furnace for instance, will, after stocking it with fresh fuel, close the draft doors long before the thermostat may indicate that the room temperature is exceeding the desired value.

The problem of automatic control of the voltage of a generator will be chosen for the purpose of illustrating some of the features of automatic control. The reader should realize, however, that similar considerations pertain to cases where

other quantities must be held constant. Incidentally, it might be of interest to point out that many controls, where the quantity to be controlled is converted into a voltage, could be considered as voltage controls. If, for instance, a 1,000 kw furnace is temperature controlled by means of a thermocouple generating perhaps 30 millivolts at the desired temperature, the closed chain could just as well be considered as a 30 millivolt generator—inefficient to be sure—the voltage of which must be held constant.

If the voltage of the generator were to be controlled manually we would have to obtain the services of an operator. We would place at his disposal a rheostat, with which he can adjust the field excitation current to any desired value, as well as an indicating voltmeter across the generator. His instructions would be to adjust the rheostat continuously in such a manner that, regardless of the amount of load, the speed of the prime mover or any other influences, the voltage of the generator remains at a constant value.

Three essentials of automatic control

In this control problem we now observe the presence of three essential elements:

1. The element to be regulated, in this case the generator with its exciting system.

2. The elements with the aid of which regulation is accomplished, in this case the field rheostat.

3. The element which regulates, which in this case consists of two components: the voltmeter and the operator acting on the rheostat. Note that the complete system represents a close chain again: the rheostat acts on the voltage of the generator, the voltage of the generator acts on the voltmeter and the operator, and the operator acts on the rheostat.

Let us assume now that the voltage of our d-c generator is to be kept at a value of 100 volts. The operator will consequently have to be provided with a meter capable of indicating this value with the desired accuracy. For an average indicating instrument the manufacturer usually guarantees an accuracy of approximately ½ of one percent. Now let us assume that we provide a magnifying glass which magnifies the part of the scale around the 100 volt point greatly. The operator might then be able to keep the pointer within a band considerably less than what the instrument claims to be ½ volt, but evidently with the limitation of accuracy as stated by the manufacturer, it is only the *sensitivity* and not the *accuracy* which has been raised by the magnifying glass.

Accuracy and sensitivity often confused

The accuracy of this system, as well as its sensitivity, depends entirely on the properties of the indicating voltmeter—under the assumption of course that the operator will do his duty. The terms "accuracy" and "sensitivity" are quite often used very loosely and, as a matter of fact, are frequently confused with each other. A great deal of effort is often made to increase the sensitivity of a given control arrangement without either a corresponding increase in accuracy, or with the mistaken idea that this automatically furnishes a higher degree of accuracy.

Using the tremendous amount of amplification possible by the use of electronic tubes, an increase of sensitivity comes cheap enough, while an increase in accuracy is still an expensive article. The difference between the meaning of accuracy and sensitivity can perhaps be best explained with the aid of a simple electrical example. In Figure 1 the current I through the resistance R, produced by the source E_o is to be regulated to any desired value by means of the rheostat R_1. Assume that the galvanometer G gives a visible deflection when a voltage of 10 micro-volts exists across its terminals. Then, if the current I is adjusted to a value so that the galvanometer reads zero, we can state that the voltage across R is within 10 micro-volts equal to the voltage of the cell E. Such an arrangement is known as a potentiometer. Since for balance $E = I \times R$, the circuit can be used for the accurate determination of any of these three quantities, provided the two others are known with accuracy.

Suppose that R equals 10 ohms $\pm$ .001 ohms, or one part in 10,000. Let E be a standard cell, with a voltage around 1 volt. At balance the product $I \times R$ is then within 10 micro-volts equal to the voltage of the standard cell, or one part in 100,000. But unless we know the voltage of the standard cell accurately, the high sensitivity of one part in 100,000 does not mean that we know the absolute value of $I \times R$ accurately to one part in 100,000! And even if the value of E were known accurately to one part in 100,000, we would not guarantee the current to more than one part in 10,000, because this is the accuracy with which R is known. Replacing the galvanometer with one that will indicate one micro-volt would increase the sensitivity, but would be an utterly useless pastime since the accuracy is the limiting factor.

A given control, then, may be capable of keeping the quantity to be controlled constant to within an extremely narrow margin without being able to give accurate information as to the *actual* value to which the variable is held. It is a relatively easy matter to design a temperature control which will be sensitive to one-hundredth of one degree but it is an entirely different matter to guarantee the actual value of the temperature within these limits. It would seem that if the thermometers used for observing the actual temperature of, say, an oil bath, are not guaranteed to more than one-quarter degree, for instance, designing a control capable of keeping the temperature within 1/100 degree of a value which we cannot guarantee to better than ¼ degree is a useless extravagance. Admittedly there may be some problems where the user is more interested in keeping the quantity at a constant value without caring too much just what this value might be, but generally speaking it seems inconsistent to demand or strive for a sensitivity of an automatic control considerably in excess of the obtainable accuracy.

BIBLIOGRAPHY

1. D. G. Prinz: Journal of Scientific Instruments, April, 1944, "Contributions To The Theory of Automatic Controllers and Followers."
2. A. Schwaiger: "Das Regulierproblem in der Elektrotechnik" B. G. Teubner, Leipzig und Berlin, 1909.
3. J. M. Cage: "Negative Feedback Amplifier Theory Applied to Regulators." Proceedings of the National Electronics Conference, 1944, page 332. (Reprinted in Electronics, January, 1945, page 140.)

SLOTTING VENTS in a large rotor shaft is accomplished with a 6 ft by 6 ft by 40 ft planer. This rotor shaft will be part of an 80,000 kw, 94,118 kva, 85 pf, 22,000 v, turbine-driven, hydrogen-cooled generator.

Protect Your Motors from *Invasion!*

MOTOR ROOM IN THE PUMPING STATION of the Little-Inch petroleum products line contains three 700 hp, 3,570 rpm induction motors to drive the pipe line pumps. Rated capacity of this 1,475-mile, 20-inch line is 235,000 barrels per day. There are 30 pumping stations on this products line, and total electric motor capacity is about 113,500 hp.

PART THREE OF FIVE PARTS*

G. BYBERG and C. LAWTON
Motor-Generator Section
Allis-Chalmers Mfg. Co.

Continuing their series, the authors outline the characteristics of the less popular base and pipe-ventilated motors.

OVER the years the search for economical protection against injurious elements has resulted in a great many types of motor enclosures and methods of ventilation, such as the more simple drip-proof, splash-proof and protected types discussed in Parts I and II. Any one of these remains popular only so long as its economical justification is not nullified by some other type or method.

Base- and pipe (self)-ventilated motors

Base- and pipe-ventilated motors fall into this classification, their popularity having waned somewhat since the advent of the totally-enclosed, fan-cooled motor. This is particularly true in the general purpose ratings where the fan-cooled type has practically supplanted the pipe-ventilated type. Base ventilation was never widely employed in this range of ratings.

Basically, ventilation of the base-ventilated and pipe-ventilated motors is the same, but mechanical structure and arrangement of inlet and outlet air duct connections are different. In general, base and self ventilation has been confined to high speed squirrel cage and wound rotor induction motors in the speed range of 500 to 3,600 rpm, for ratings 250 hp and larger. An occasional synchronous motor is also cooled in this manner and, where conditions are favorable, base ventilation can be used for some larger high speed d-c motors.

Motors are self-ventilating because their rotor fans are sufficiently large to circulate the air effectively through a duct sys-

* Parts One and Two of this series appeared in the September, 1944, and March, 1945, issues of the *Review*.

tem. They are simple, therefore, in operation and require no external ventilating equipment with its necessary maintenance.

Both the pipe-ventilated and base-ventilated types (Figures 1 and 2) are totally enclosed except for openings provided for the admission and discharge of cooling air which is circulated by means integral with the motors. In the case of the pipe-ventilated motor, these openings are so arranged that inlet and outlet ducts are connected to them, while in the base-ventilated motor air is drawn in from and discharged through the base to a room below, which is provided with cool, clean air. The duct system for these types of motors should be relatively straight, of ample section, and usually specified no longer than 25 feet, although for higher speed machines of 1,200 to 3,600 rpm, it is frequently possible to use much longer ducts, depending upon duct pressure drop and capacity of the rotor fans.

In locations where the ambient temperature is high, clean, cool air may be taken from another part of the building or from the outside and discharged into the room. Occasionally the warm discharged air is used for heating purposes during the winter months. In warmer climates where warm air is not desirable within the building, the ventilating air may be taken in as in the normal standard open motor and discharged outside of the building through a duct.

Long ducts need special rotor fan

There are often cases where it may seem desirable to use very long ventilating ducts but it is doubtful if the machine can develop the pressure necessary to handle the required volume of ventilating air. In such cases, the size and speed of the motor may be high enough to render a special rotor fan design adequate, for the higher the speed of the motor the more probable it is that it will be able to handle these border line conditions. In such instances the motor manufacturer should be consulted advising the details with sketches of the proposed duct system.

Because of the considerable cost of this type of construction, it is generally economical only in the larger motor ratings where large quantities of air must be handled. Below 250 hp a totally-enclosed fan-cooled motor is more economical. In larger sizes the pipe-ventilated motor will cost from 60 to 75 percent as much as the totally-enclosed fan-cooled type, excluding the cost of installing suitable duct work, which in the aggregate may approach the cost of totally-enclosed fan-cooled motors.

Because some types and ratings of rotating machines are incapable of self-ventilation below certain limits of low speeds and also because some forms of protective enclosures restrict natural ventilation, it is quite frequently imperative that ventilation be obtained from an external source. The ASA Standards gives the following definition: "A separately ventilated machine is one which has its ventilating air supplied by an independent fan or blower external to the machine."

This general definition may be applicable to a number of varying conditions of application requirements, such as:

(a) The machine may be of the *open* type, so located that self-ventilation is difficult or impossible, because of space restrictions or excessive ambient temperatures. In such cases the necessary ventilating air may be supplied to the room or machine space from an external source by means of a fan or blower, or the heated air may be withdrawn from the room or machine space by means of an exhaust fan.

(b) A machine may have either inlet or outlet ducts for the ventilating air but no protective enclosures other than for the bare essential of directing the air into the room through the same paths or openings as in an "open" machine, or withdrawn from it by means of an exhaust fan. Integral ventilating equipment described below may also be applied to this condition.

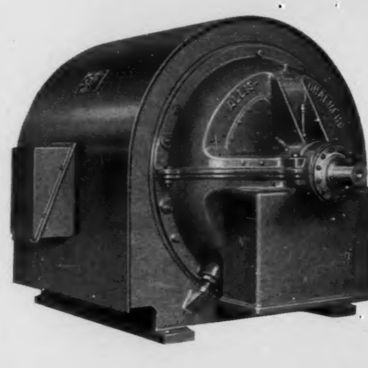
(c) It may be a machine that is enclosed, separately-ventilated.

Condition (a), the open-type motor, is self-explanatory and seldom encountered. Thus, the enclosed separately-ventilated types will be discussed and it should be noted that comments under non-recirculating systems are also applicable to condition (b).

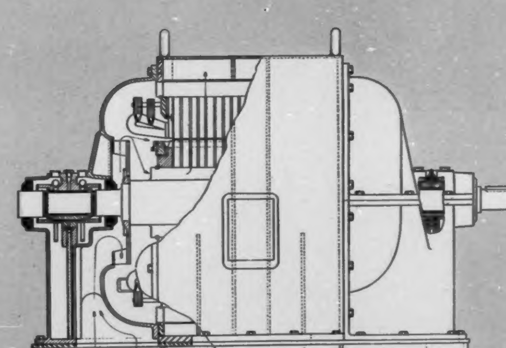
Enclosed, separately-ventilated machines

"An enclosed, separately-ventilated machine is a machine having openings for the admission and discharge of the ventilating air, which is circulated by means external to and not part of the machine, the machine being otherwise totally enclosed. The openings are so arranged that inlet and outlet duct pipes may be connected to them," according to the American Standards Association.

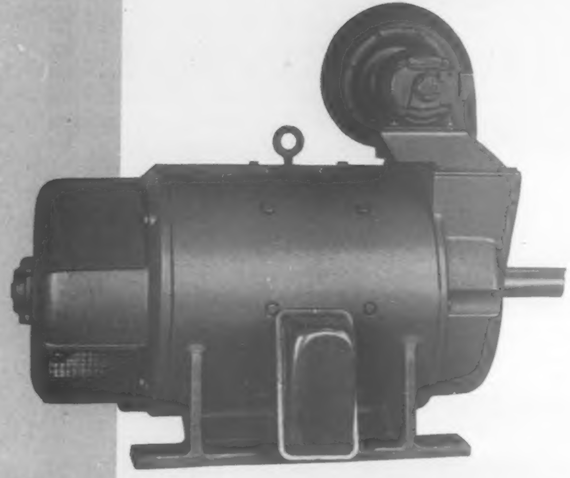
For separately-(forced) ventilating rotating machinery two distinct methods or systems are used, each having a fairly well defined field of application permitting modifications to suit particular conditions to be met.



PIPE-VENTILATED motor has air intake at both ends and discharge at the sides. Intakes can be arranged to take in air from above instead of below. (FIG. 1)



BASE-VENTILATED squirrel-cage motor shows ventilation in cross-section. Air pressure within bearings is equalized to prevent drawing of oil into motor by rotor fan action. (FIGURE 2)



PLANER MOTOR with integral ventilating equipment takes air in through the opening in rear end bearing bracket and discharges it through the "protected" lower openings in the front bracket. (FIGURE 3)

INTEGRAL VENTILATING EQUIPMENT for non-recirculating system of a drag-generator for temper pass mill consists of cage motor driven blower with spun-glass filter placed ahead of air intake. (FIGURE 4)

SEPARATELY — (FORCED) VENTILATED d-c motor is designed so the rear end bearing bracket can be connected to the incoming air duct. Air discharges through bottom openings in front bearing bracket. (FIG. 5)

(1) Non-recirculating systems with blowers (or exhaust fans)

With or without air-coolers.

With or without air-filters or air-washers.

(2) Recirculating systems with blowers.

Always with air-coolers.

With or without air-filters or air-washers.

In all cases the machine rating remains the same as for an open self-ventilated type, when that type is operating under conditions providing suitable ventilating air. Thus, a machine rated 2,000 hp, 40 C rise, open, self-ventilated, will have that same rating when enclosed and separately ventilated.

The reverse is not always true, however. A machine designed especially for forced-ventilated operation may not necessarily be capable of carrying its rated load and maintaining guaranteed temperature rise if it is operated as an open machine. Certain low speed reversing motors cannot conveniently be designed except as forced-ventilated machines.

Non-recirculating systems

In a non-recirculating system the ventilating air, after performing its function, is discharged from the machine into the room or outside of the building. If the intake air is of too high an ambient temperature an air-cooler may be desirable; if the air is excessively dusty or dirty it is recommended that filters or washers be used. Hence depending upon conditions, either or both adjuncts may be essential.

This type of system is predominantly used and, although it lacks some of the refinements possible with the costlier recirculating system, it is eminently suitable for most conditions of installations.

One of the most convenient forms of the non-recirculating system, for machines or smaller and intermediate sizes, is provided by means of a motor-driven blower mounted on the machine frame. Practically any type of machine which is incapable of ventilating itself even as an open type because of inherent low speed can be so arranged.

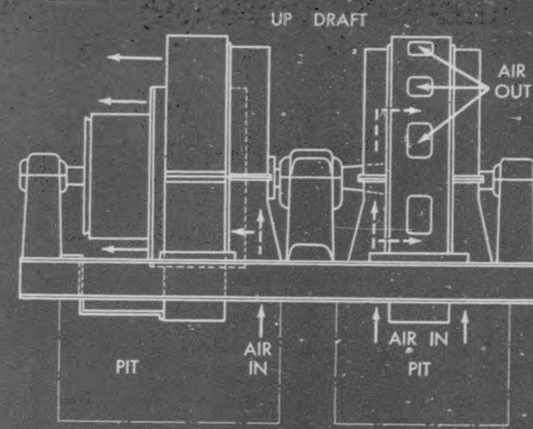
This applies particularly to smaller d-c machines operating over wide speed ranges, such as, for example, planer motors or large, low-speed reversing motors where the armature diameter is restricted by low moment of inertia requirements. Some extreme examples are the speed-regulating motors of either frequency-converter or Rossman drives, which at some point of the main drive speed range may actually be near zero speed with full field and full or partial armature current flowing.

Numerous examples of this kind will be encountered in drag-generators for temper-pass mills, slush-pumps in oil-field service, low-speed ship propulsion motors, etc. Typical arrangements are shown by Figures 3 and 4.

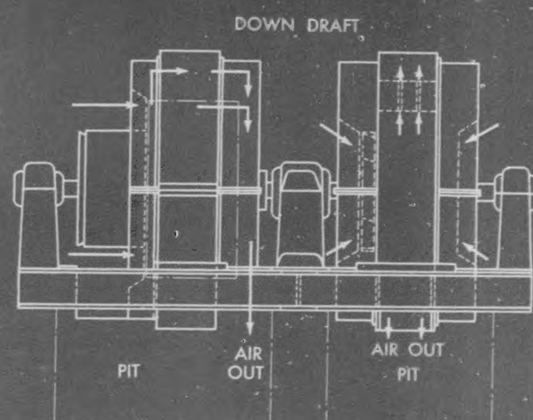
Likewise, a constant-horsepower or constant-torque multi-speed squirrel-cage induction motor having a wide range of speeds (for example 1200/720/600/360 rpm) may have its low speed ventilation impaired because of restrictions imposed on the rotor diameter by its highest speed. In a case of this kind, integral equipment could be arranged to cut in automatically when the motor is operating at low speed.

The simplest forms of enclosed machines for non-recirculating systems having the ventilating equipment separate from the machine are shown in Figures 5 and 6. In Figure 5 the

SEPARATELY-VENTILATED synchronous or induction motors have top connections for incoming air ducts made integral with stator yoke. Air discharges at bottom of each yoke side. (FIG. 6)



NON-RECIRCULATING "UP-DRAFT" SYSTEM is here arranged for a large synchronous motor-generator set. (FIGURE 7)



"DOWN-DRAFT" MACHINE CONSTRUCTION for recirculating systems is one method for dissipating heat. (FIGURE 8)

bottom half openings in the front bracket, through which the heated air discharges, can be left open or connected to discharge ducts as desired. The top openings in the front bracket are covered, but if discharge ducts were used these covers could be transferred to the bottom half openings and the discharge ducts connected to the top openings, if so desired.

In Figure 6 the air intake connections are part of the stator yoke, providing an advantageous arrangement since it permits access to the internal parts of the machine without disturbing the duct connections.

It may be asked why this method should be used for individual smaller machines when frame-mounted, integral equipment is available. Often, however, the machine is located in surroundings where the ambient air is too warm for ventilating purposes, or contains injurious elements. For example, in certain rubber mill operations, lampblack may be present in such quantities that the filter of an integral equipment would quickly become clogged and require too frequent replacement.

In the case of larger machines the non-recirculating system is usually arranged to supply air under pressure to a basement or machine pit. The pit and the machine room must then, of course, be separated from each other by means of floor or base plates, so that the ventilating air cannot mix with the room air until it has passed through the machine.

Thus, to make efficient use of this system, all machines must be equipped with suitable covers on at least one end to confine and direct the flow of cooling air. It is the practice, therefore, to take in the ventilating air from the pit through end covers on the machines and discharge it into the machine room from where it escapes. In the case of a-c machines air intake covers are usually provided on both ends of the frame and the air discharges through openings in the stator yoke. For d-c machines the air comes in through the rear end cover and discharges through the front or commutator end.

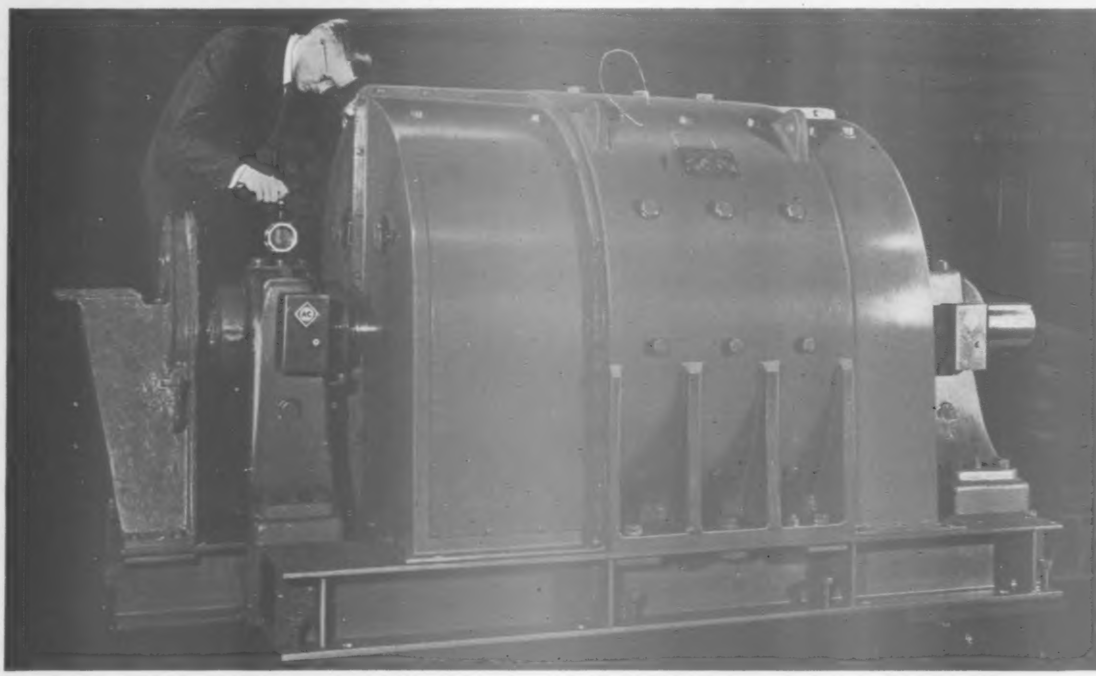
So far as arrangement of the machine enclosures are concerned there is no difference between the conventional non-recirculating and the "recirculating, up-draft" system described below. Figure 7 shows an arrangement of this kind for a large synchronous motor-generator set.

Recirculating systems

By continuously recirculating the required volume of air through the machines and surface air-coolers (and filters or washers, when used) by means of separately mounted fans or blowers, a recirculating system dissipates heat generated in electrical apparatus. Self-ventilating machines with recirculating systems will be discussed in Part IV. Depending upon the importance of the installation, local conditions, building structure, and preference of the plant engineers, the equipment may be designed for one of several possible arrangements:

(1) "Down-draft" — in which the cool, clean ventilating air is forced into the motor room, drawn into the machines where it picks up the generated heat, passes into the pit or basement, and goes through the ductwork to the surface coolers where the heat is transferred to the cooling water. Figure 8 is typical of machine construction in this system. Enclosing covers for a-c machines will be designed to take in air along the shaft at both ends and discharge it through the lower part of the stator yoke. In d-c machines the air enters the commutator end, deflector covers generally being used to properly direct the flow of air over the commutator and through armature, and discharges into the pit through the rear end covers.

(2) "Up-draft"—in which the flow of air is reversed from that in the down-draft, going from the blower into the ductwork to the basement or machine pits, then through the machines into the machine room from whence it returns to the



TYPICAL MACHINE FOR CLOSED RECIRCULATING SYSTEMS is this d-c motor designed for metal-rolling mill service. Air enters rear cover, passes through motor, and discharges through front cover into a pit for cooling and filtering. **(FIG. 9)**

coolers and filters. For machine construction typical of this system see Figure 7.

(3) Machines in a closed recirculating system with the ventilating equipment and the machines completely enclosed above the floorline are shown in Figure 9. This arrangement may be used where individual machines are so located that separate machine rooms using (1) or (2) are not permissible, but where it is necessary, nevertheless, to protect and ventilate the equipment properly. While the enclosures are not necessarily airtight, there will be little leakage and the pressure within serves to keep out dust and fumes. For a-c machines air is taken into the end covers and discharged through the bottom of the stator yoke; in the case of d-c machines, taken in through the rear and discharged downward through the front end cover.

It is clear that recirculating systems may be used for one or for a number of machines using a common air-cooler and blower system. Where a number of machines are served by a common system, a "make-up" blower and filter is usually necessary since no machine room, or machine enclosures, are absolutely airtight. The capacity of this make-up unit should be approximately ten percent of the total volume circulated by main blowers to make up for leakage losses, at a pressure of about one inch water gauge. For down-draft or up-draft arrangements this make-up blower may serve to maintain the air of a fairly tight machine room at slightly above atmospheric pressure and thereby tend to prevent the infiltration of dust and dirt. Where each machine, or the machines of a motor-generator set, are served by an individual ventilating system, no make-up blower unit is needed.

The *volume* of air required is a direct function of the losses in the machine and the air temperature. Where proper enclosing directional covers are provided on the machine this amount will vary from about 100 to 125 cubic feet of air per minute per kw loss at the standard reference ambient of 40 C. Where the air is simply blown into a machine space or room for an open machine, the volume required may be considerably higher since there is then no assurance of full utilization of the air.

The air *pressure* required is subject to a greater range of variation, being dependent upon the particular type and speed of the machine itself, whether the blower is individual to the machine, or whether ductwork of any appreciable length is used upon the pressure drop in the ducts. When air-coolers and filters are used, the pressure drop through these components must also be taken into consideration.

In the case of a high-speed machine, which as an open type is readily capable of ventilating itself, a pressure of one-half inch water gauge at the air inlet may be sufficient, providing the air is discharged from the machine against atmospheric pressure only. But a low-speed machine, incapable of ventilating itself as an open type, may under the same conditions require a pressure of several inches. Likewise, the addition of longer ductwork, air-coolers, and filters may serve to bring the required pressure up to three or four inches and perhaps even higher.

OSCAR A. HAAS,
ASSISTANT MANAGER
BLOW